MIDDLE PALEOGENE PALYNOLOGY OF COLOMBIA, SOUTH AMERICA: BIOSTRATIGRAPHIC, SEQUENCE STRATIGRAPHIC, AND DIVERSITY IMPLICATIONS

By

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A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

1999

ACKNOWLEDGMENTS

First and foremost, I wish to thank my advisor, Dr. David L. Dilcher. His advice, encouragement, constructive criticism, and help were instrumental in the success of this project. I would like to thank the members of my committee Drs. David Hodell, Douglas Jones, Walter Judd, Steven Manchester, and Neil Opdyke for their continuous support. I am grateful to Germán Bayona for his assistance during the field season. Thanks go to Drs. Fernando Etayo and Tomás Villamil for encouraging me to pursue a Ph.D. I would like to thank Dr. David Jarzen, and Ricardo Holdo for discussion about palynological and statistical matters. The Corporación Geológica Ares provided valuable logistic support.

This study was funded by the National Science Foundation, Colciencias, the Fundación para la Promoción de la Investigación y la Tecnología Banco de la República, the Geological Society of America, the American Association of Petroleum Geologists, the American Association of Stratigraphic Palynologists, the University of Florida's College of Liberal Arts and Sciences, the Department of Geology, and the Florida Museum of Natural History.

My gratitude goes to Rodolfo Dino from Petrobras, Henry Hooghiemstra from the University of Amsterdam, Roel Verreussel from the University of Utrecht, and Estela de DiGiacomo from Pedevesa, for allowing me to visit their palynological collections. Graham Williams and Jonathan Bujak helped me with the dinocyst identifications. I am also grateful to all the people who helped me during my field season in the towns of Sabanalarga, Uribe-Uribe, and Cúcuta.

Special thanks go to my parents who have patiently supported me through the many years of my schooling, and to my wife, Maria Inés Barreto, who has kept me alive.

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Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

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August 1999

Chairman: David L. Dilcher
Major Department: Geology

The late Paleocene-early Eocene interval is characterized by a long period of global warming that culminated with the highest temperatures of the Tertiary. This time interval is associated with plant extinctions and a subsequent increase in plant diversity in mid and high latitudes. However, data from tropical regions remain largely unknown. This time interval is also of strategic interest in northern South America because most oil reservoirs occur in Paleogene strata where detailed chronostratigraphy is necessary to develop a clear understanding of stratigraphy and structural geology.

I analyzed the palynostratigraphy of three areas in the Colombian Eastern Andes (northern Middle Magdalena, Llanos Foothills, and southern Catatumbo) with the aim of achieving three major goals: a) to produce a time-framework using pollen, spores, and dinoflagellates; b) to develop a sequence stratigraphic interpretation for each section using palynofacies, paleoecology, and lithofacies; and c) to look for patterns of pollen and spores diversity through the late Paleocene-Eocene interval.

A biostratigraphic framework was built using graphic correlation. Dating sections indicate that there is not a significant time gap encompassing the early and middle Eocene in

all of Colombia as previous authors had interpreted. Also, it is clear that formational boundaries of the Paleocene-Eocene formations do not correspond to epoch boundaries and cannot always be considered as chronostratigraphic surfaces. Sequence stratigraphic interpretations of each section indicate that it is not possible to establish a single sequence stratigraphic model for the three sections because they were in three different basins, isolated from each other, and with different subsidence histories, sediment sources, and stratal architecture. However, there are two events with regional significance: an earliest Eocene sequence boundary, and an early middle Eocene flooding surface.

The pollen/spores record indicates a relatively large extinction at the end of the Paleocene and a subsequent increase in diversity during the early and early middle Eocene reaching levels higher that those of the late Paleocene. This extinction and subsequent increase in diversity may be correlated with the late Paleocene Thermal Maximum and Eocene Thermal Maximum, respectively. This demonstrates that variability in tropical climate may have played an important role in the development of plant diversity in the neotropics.

CHAPTER 1
INTRODUCTION

Colombian stratigraphy is mainly composed of Tertiary continental sedimentary rocks. These strata are in structurally complex areas related to the Pliocene Andes uplift further complicating an adequate understanding of the Tertiary stratigraphy. For the last 60 years, intensive geological exploration of Colombian Tertiary rocks has been carried out. Most of this work has been related to oil exploration. Unfortunately, only a small fraction of this information has been published.

The Paleocene-Eocene history of northern South America has been the focus of many researchers since the 1950s (Van der Hammen, 1954; Gonzalez, 1967; Muller *et al.*, 1987). Still, this time interval remains poorly known and more detailed geologic research is necessary. Important large-scale events developed during the Paleogene such as the Eocene Thermal Maximum (Miller *et al.*, 1987), the Andes uplift process (Etayo-Serna *et al.*, 1983), and the initial closure of the Tethys. More information on those subjects from neotropical areas is necessary for an adequate understanding of them. The Paleogene history of northern South America is also important regionally because the most important hydrocarbon reservoirs in the region are located in Paleocene and Eocene continental rocks. These reservoirs are frequently located in zones with high structural complexity where an excellent biostratigraphic framework is crucial toward understanding the stratigraphy, defining oil-bearing structures, and planning new exploration targets.

Three subjects in need of more intensive research are evident in the geology of this area: lack of a high-resolution chronostratigraphic framework, lack of basin-focused sequence stratigraphic models, and the unknown effects of the Eocene Thermal

Maximum on tropical vegetation. These three problems could be addressed using fossil data coupled with stratigraphic analyses.

The most abundant fossils present in the Paleogene sediments of continental Colombia are palynomorphs and particulate organic matter. The word "palynomorph" is used here to indicate pollen, spores, and dinoflagellates; "sporomorph" indicate pollen and spores, while "palynofacies" indicates the assemblage of particulate organic matter (Traverse, 1988). Relatively little published information exists on Colombian palynology; this may be due to the confidentiality of information used by various oil companies operating in the area. However, previous palynologic studies in the region (Gonzalez, 1967; Germeraad *et al.*, 1968) reported highly diverse and abundant pollen/spores assemblages and showed that sporomorphs are the most reliable biostratigraphic and paleoecological tool in terrestrial Paleogene strata of Colombia.

One of the major problems in integrating geologic information produced in neotropical areas, especially Colombia, with the rest of the world is the lack of a truly high resolution chronostratigraphic framework. For the last 30 years, a local system for placing events in a temporal order has been developed in the tropics. This system for the Paleocene-Eocene interval relies on pollen and spores because they are the most abundant fossils in continental deposits accumulated during this time. However, this system has a low resolution for the Paleocene-Eocene and it is poorly correlated with the international time scale. This time scale provides a single universal reference standard for dating rock strata or events in earth history with respect to the passage of geologic time (Berggren *et al.*, 1995a). In other words, what tropical American geologists often call "late Paleocene", "early Eocene", etc., must be taken with caution, and be considered an informal name that does not bear exactly the same meaning as in the standard geologic time scale. A high resolution chronostratigraphic framework calibrated with the geologic time scale is urgently needed. Only then, can we truly start to use and integrate the geologic information produced in neotropics with the rest of the world.

An adequate understanding of the pollen and spores distributions as well as the facies control on their distributions require a stratigraphic understanding of the rocks containing them. Sequence stratigraphy has become the most reliable tool for studying strata in clastic sedimentary basins. Sequence stratigraphy is the study of genetically related facies within a framework of chronostratigraphically significant surfaces (Van Wagoner *et al.*, 1990). This modern approach is widely used to study the hierarchical arrangement and spatial distribution of sedimentary deposits. Sequence stratigraphy was done using palynofacies, palynomorph paleoecology, and lithological analyses. The sequence stratigraphy analysis provided hypotheses for the general patterns of strata distribution and the geographical extent of transgressive and regressive episodes.

The effects of the Eocene Thermal Maximum on tropical vegetation are still unknown, but important for a full understanding of the climate and its effects on biota during this unique time in earth's history. One the best tools to study tropical vegetational changes are pollen and spores (Traverse, 1988). Pollen and spores provide a more continuous record of vegetational change than can be had from megafossils, particularly in tropical areas where megafossil plant remains are usually not well preserved. Large climatic variations in terrestrial tropical environments could lead to changes in vegetation that would be recorded by the fossil record of pollen and spores.

In the present study the palynomorph distributions and palynofacies across the late Paleocene-Eocene in the eastern Andes of Colombia are presented with the aim of producing high-resolution biostratigraphy, proposing sequence stratigraphy models for the area, and identifying any changes in pollen and spores diversity across the Eocene Thermal Maximum.

CHAPTER 2
OBJECTIVES

This project was undertaken to analyze the palynological biostratigraphic distribution and sequence stratigraphy of three Paleogene sections in the Eastern Andes of Colombia (Fig. 3-1). The main objectives of this study were:

1. To complete a detailed taxonomic analysis of palynomorphs present in these sections.

2. To build a high resolution biostratigraphic framework for the late Paleocene-Eocene interval based on the occurrence and abundance of these palynomorphs.

3. To use palynofacies, palynomorph paleoecology, and lithofacies to propose a preliminary sequence stratigraphy model for each section.

4. To analyze the various patterns of sporomorph (pollen and spores) diversity throughout the middle Paleocene-Eocene of the Eastern Andes of Colombia. These assemblages also were compared to palynofloras in Central America, U.S. Gulf Coast, and tropical Africa during the Paleocene-Eocene.

CHAPTER 3
MATERIALS AND METHODS

Three stratigraphic sections were studied in the Eastern Andes of Colombia (Fig. 3-1). The first section is located in the Llanos Foothills, along Piñalerita creek near Sabanalarga, 73° 1' W - 4° 54' N, where the Paleogene sequence comprises, from older to younger, the Barco-Cuervos Group (180 m), the oil-rich Mirador Formation (70 m), and the San Fernando Formation (300 m). The second section occurs in the eastern middle Magdalena Valley, along the Rio Negro river, near Uribe, 7° 20N - 73° 20W. The third section is located in the Catatumbo area, south of Cúcuta, Near La Donjuana, along the Regadera Creek, 72° 37' W - 7° 42' N.

These sections were measured and described in detail (scale 1:100), recording major physical and biogenic sedimentary structures. The Jacob's staff method was used to measure the sections (Miall, 1984). This method allows for high resolution in sampling and detailed descriptions of stratigraphic sections. A staff was constructed of a 1.5m wooden rod, with a Brunton compass attached to the tip. The clinometer of the compass was preset at the measured structural dip of the strata in the section, thus the staff can be used to measured the stratigraphic thickness of the section. The staff was always positioned perpendicular to the bedding plane. A consecutive number was marked on the rock with red paint as the measuring of the section advanced upward in the section. These numbers were used as a reference system for describing the section and collecting samples for palynological processing. Rock samples were collected at five to ten meter intervals, for palynologic purposes, a reasonable sampling interval given the thickness of the analyzed sections (averaging 700m/section).

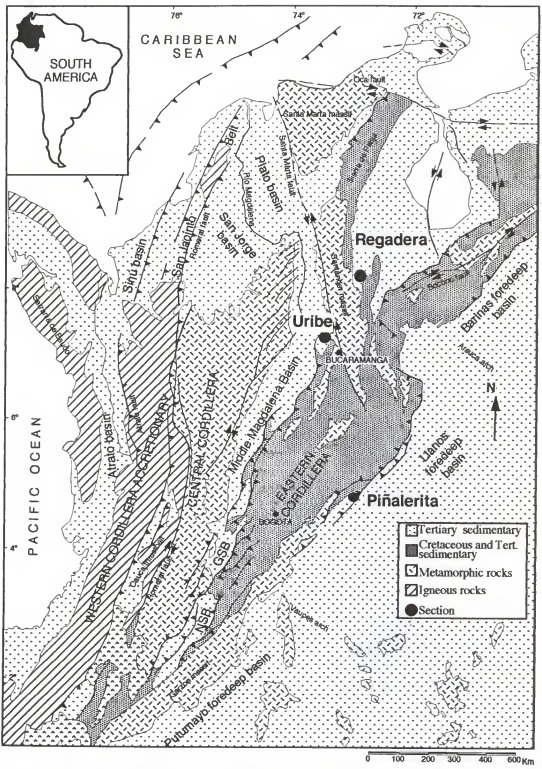


Figure 3-1. Geologic map of Colombia showing the three sections studied (modified from Dengo and Covey, 1993).

The palynologic samples were prepared by the standard procedure of digesting sample in HF and HCl acids, separating organic matter by heavy liquids, and oxidizing with Schultz solution (Traverse, 1988). This method was specifically modified by Russ Harms from Global Geolab, who prepared most of the samples (Global Geolab 729B-15th Street S.W., Medicine Hat, Alberta T1A 4W7, Canada). Twenty-five grams of sample were placed in a 250 ml polypropylene beaker along with a *Lycopodium* tablet. The *Lycopodium* tablets were used to have absolute concentrations of pollen per gram of sediment (Traverse, 1988). The specific weight for each sample was measured and recorded. A 10% solution of HCl was then added and left, generally overnight, allowing carbonates to dissolve. The HCl was decanted and washed 3 times with distilled water to remove remaining calcium ions that can flocculate when HF is added. Then, 70% HF was added to the sample. The sample was agitated for 4 hours until digestion was completed. The digested sample was poured into a 50 ml. polypropylene test tube and centrifuged for five minutes at 2000 rpm. The top 3/4 was then decanted, and distilled water was added while vortexing and the sample was centrifuged for two minutes. Distilled water was added until the solution was neutral. The next step consisted of adding 5 ml of Darvan, vortexing while adding distilled water and centrifuging for one minute at 2000 rpm. This washing/centrifuging was repeated until the fine clastic material was removed (3 or 4 times). A few drops of concentrated HCl were added for a better heavy liquid separation, vortexing while adding water and centrifuging for 4 minutes. The heavy liquid separation was done using $ZnBr_2$ (gravity 2.0). Twenty-five ml of $ZnBr_2$ were added to the sample, which was then vortexed thoroughly. The test tube was placed in an ultrasonic bath for ten seconds. Samples were allow to sit for ten minutes before centrifuging for 15 min. at 2000 rpm. The floating part was then poured off into another 50 ml tube, and washed and centrifuged three times for 2 min. at 2000 rpm. The residue was then transferred to a 20 ml glass tube and a first slide for palynofacies analysis was made. The residue was examined for the amount of oxidation

required. Three ml of Schultz solution were poured in the tube with the residue, vortexed, and placed in a hot water bath for 4-12 min. Schultz was removed and the samples washed three times until the solution was neutral. A 10% NH_4OH solution was then added and placed in a hot water bath for 2 minutes. The sample was washed and centrifuged three times, was then sieved using a 7um nitex screen cloth. The sieved fractions were pipetted off and mixed in one drop of polyvinyl alcohol with a glass stirring rod. When the polyvinyl was dry, one drop of clear casting resin was added and the coverslip was turned and sealed. Permanent curing occurred in one hour.

A Carl Zeiss light microscope (Scope 2, #4311267, Paleobotany Laboratory, Florida Museum of Natural History) was used for palynologic analyses. At least one complete oxidized slide per sample was scanned with a 40x Zeiss planapochromatic objective and 300 palynomorphs per slide were counted when possible. Examination of the fossil taxa was done using a 100x Zeiss oil immersion planapochromatic objective. Slides are deposited in the Paleobotanical collection of the Florida Museum of Natural History.

Identification was done through comparison with published photographs and descriptions, and the holotype material in the palynological collections of University of Amsterdam (Holland), Petrobras in Rio de Janeiro (Brazil), and Pedevesa in Caracas (Venezuela). I attempeted to consult the holotypes of the collections of Enrique Gonzalez in Venezuela and Gustavo Sarmiento in Colombia. However, these collections could not be observed because they are poorly preserved and inaccessible (Gonzalez, personal communication), and have been misplaced in the Ingeominas, Bogotá (Sarmiento, personal communication). Many of the holotypes I observed were badly damaged, especially those described before 1970, and I had to rely on the published descriptions and photographs.

Published papers on the U.S. Gulf Coast, Central America and tropical Africa were used as the main sources of the comparative study between the Paleogene of Gulf

Coast, Colombia, and Africa Palynoflora of northern South America was compared with assemblages from U.S. Gulf Coast, Central America and tropical Africa (Van Hoeken-Klinkenberg, 1966; Germeraad *et al.*, 1968; Elsik, 1968a,b, 1978; Graham and Jarzen, 1969; Srivastava, 1972; Tschudy, 1973; Elsik, 1974; Elsik and Dilcher, 1974; Adegoke and Jan du Chene, 1975; Potter, 1976; Graham, 1977, 1985, 1993, 1995; Jan du Chêne and Salami, 1978; Salard-Cheboldaeff, 1978, 1979, 1990; Jan du Chêne *et al.*, 1978a,b; Frederiksen, 1980; Martínez-Hernández *et al.*, 1980; Potter and Dilcher, 1980; Medus, 1982; Tomasini-Ortiz and Martînez-Hernández, 1984; Mebradu *et al.*, 1985; Salami, 1985; Schrank, 1987; Frederiksen, 1988; Ventatachala *et al.*, 1988; Westgate and Gee, 1990; Oloto, 1992; Awad, 1994; El Beialy, 1998).

A time-framework based on the stratigraphic distribution of palynomorphs was developed, using graphic correlation (Shaw, 1964; Edwards, 1984; Edwards, 1989). This is a method of correlating fossil occurrences based on interpretation of graphic plots of first and last appearances of taxa. This is a powerful method because it does not assume *a priori* that first and last appearances of chosen taxa are synchronous, as the traditional biostratigraphic zonations do. It also allows the production of high-resolution chronostratigraphic frameworks (Pasley and Hazel, 1995; Jaramillo and Oboh, 1999). The two most complete sections were plotted against each other and last and first appearances of all taxa presented in both sections were then compared and plotted (see Chapter 5). A line of correlation was then plotted. The ranges of the taxa were compared with the correlation line and extended up and down section when necessary producing a Composite Section. This Composite Section was then compared with additional sections in the same way. The process was repeated several times until the range of each taxon was stable and did not extended up or down anymore. The final result was a Composite Section that contained the longest range possible for each taxon. This method, however, tends to artificially extend taxon ranges, but this artifact is usually balanced by the variations in sample spacing and probability of finding particular taxa in all possible

samples (Edwards, 1984). The units of this Composite Section are composite units that represent time. They were then calibrated against the geologic time table using foraminiferal datums and radiometric datings.

Palynofacies analyses were only undertaken with non-oxidized slides. The oxidation process alters the natural colors of dispersed organic matter (palynodebris) and destroys certain organic matter types, such as structureless amorphous material (Traverse, 1988). At least 300 organic particles were counted per slide. In the absence of a standard palynofacies classification system, one adapted from Lorente (1986), Van Vergen *et al.* (1990), Oboh (1992), and Jaramillo and Oboh (1999) was used This system classifies dispersed organic matter based on morphological differences seen under a light microscope. The classification scheme is outlined below (see also Table 3-1).

a. Aquatic organic matter that comprises the following:

a.1 Structureless amorphous material. They are gel-like and exhibit a "clotted" appearance (Tyson, 1995).

a.2 Dinoflagellates and foraminiferal wall linings. Most fossil dinoflagellate cysts indicate marine environments (Evitt, 1985).

b. Terrestrially derived material that comprises:

b.1 Structureless material

b.1.1 Resins. Unstructured amber-color fragments.

b.1.2 Black debris. Opaque particles without internal structure, and usually angular shape. Sometimes called charcoal, black wood, or inertinite.

b.1.3 Yellow-brown material. Structureless particles of yellow to light brown color. This material could be attributable to highly degraded herbaceous material

b.1.4 Black-brown material. Unstructured dark brown material, which could be attributable to highly degraded woody material.

b.2 Structured material:

b.2.1 Cuticles. Cuticles are extra-cellular layers covering the epidermis of higher plants. Well preserved showing clear structure of epidermal cell outlines.

b.2.2 Plant Tissue. This group includes all kinds of plant tissue material, with the exception of cuticles and well-preserved woody material. Collenchyma and parenchyma cells are included in this group.

b.2.3 Woody material. Particles with brown color, sharp angular edges and discernible cellular structure.

b.2.4 Pollen and spores.

b.2.5 Fungi. This group includes all fungal remains such as hyphae, fruiting bodies, and fungal spores.

Fluorescence was used for distinguishing between amorphous marine and degraded terrestrial organic matter. Marine amorphous is fluorescent, while the terrestrial amorphous is not fluorescent (Lorente, 1986).

Palynofacies data were analyzed using multivariate statistical techniques. A Euclidean-distance cluster analysis with average linkage was performed on the palynodebris percentage data and used to develop a palynofacies model, which was then correlated with changes in depositional environments. The Euclidean distance is especially designed to work with continuous or ratio scales (SYSTAT, 1992). Moreover, the linkage averages all distances between pairs of objects in different clusters and decides how far apart they are (Sokal and Michener, 1958).

Paleoecological analysis of palynomorph abundace distribution was done using multivariate statistical techniques. Other methods as the Nearest Living Relative are very difficult to apply with pollen and spores in pre-Oligocene sediments (Traverse, 1988), although with a few exceptions (e.g., *Spinizonocolpites* pollen that is a close relative of extant *Nypa*, a mangrove palm of South East Asia, Germeraad *et al.*, 1968). The use of multivariate statistical techniques such as Principal Component Analysis, Multidimensional Scaling, or Cluster Analysis relies on the basic assumption that

Table 3-1. Organic matter classification (adapted from Lorente 1986; Van Vergen *et al* ., 1990; and Jaramillo and Oboh, 1999).

Category	Palynodebris	Description
Aquatic (structureless	Structureless amorphous material	Gel-like and exhibit a "clotted" appearance (Lorente, 1986)
Aquatic (Structured)	Dinoflagellate cysts and foraminiferal wall linings	Marine microphytoplankton and chitinous internal linings of foraminifera; linings usually spirally-coiled
Terrestrial (Structureless)	Resins	Unstructured amber-color fragments normally derived from stem tissues of gymnosperms
	Black debris	Opaque particles without internal structure; have sharp angular edges or are lath-shaped; called black wood, charcoal and/or inertinite by several workers
	Yellow-brown fragments	Structureless particles of yellow to light brown color attributed to highly degraded herbaceous material
	Black-brown fragments	Unstructured dark brown material, which is attributed to highly degraded woody material
Terrestrial (Structured)	Cuticles	Cutin layer covering the epidermis of higher plants; well preserved and showing epidermis outline
	Plant Tissue	This group includes all other herbaceous material, with the exception of cuticles; collenchyma and parenchyma are included here
	Woody material	Brown particles with sharp angular edges and discernible cellular structure
	Pollen and spores	Spores belonging to pteridophytes and pollen of gymnosperms and angiosperms
	Fungi	This group includes all fungal remains, such as hyphae, mycelia and non-embryophitic spores

pollen/spores that co-occurred in the same samples lived in similar environments, and that statistical parameters evaluate how strong a given co-occurrence is. This approach allowed testing of previous hypotheses for specific paleoenvironments. In addition it provided new hypotheses of palynomorph-environment relationships that can be tested in future studies.

The choice of which multivariate analysis to perform on any dataset depends upon the structure and noisiness of the data, the specific question being addressed, and the philosophy behind the study (Kovach, 1989). While considering a problem similar to the one being addressed in this study, Kovach (1989) analyzed a noisy and non-normal dataset, to relate species distribution to a terrestrial-marginal marine gradient, as well as to infer what groups characterized each environment. He found that the best method, which provides an unambiguous answer to the question (Pielou, 1984), was the Spearman rank-order coefficient performing a multidimensional scaling (MDS) analysis.

Spearman is a non-metric, quantitative similarity measure in which correlations are made based on the rank-order of the abundances rather than absolute values. Thus, variations in abundance due to noisy data or closure effect do not strongly affect this coefficient (Kovach, 1989) as with metric coefficients. It is effective in paleoecological studies because it places more weight on elements that are farther apart, while close ranks have little affect on the correlation (Sokal and Rohlf, 1981). Multidimensional scaling (MDS) is a multivariate statistical technique that is designed to construct a "map" showing the relationships between a number of objects, given only a table of distances between them (Manly, 1994). It makes no assumption of normality or linearity of the data (Kovach, 1989). It bases the ordination on the rank-order of the elements of the similarity matrix, rather than their absolute values. The basic assumption is that the greater the similarity between two objects, the closer they should be to each other in the ordination (Kovach, 1989). A value, called stress, measures the fitness of ordination to original similarities, the lower the value the fittest ordination. This method requires in

advance the number of dimensions to be used. Using the wrong number of dimensions, however, can distort the results, but generally using 2 or 3 dimensions show little distortion of this sort (Kendel and Orlocci, 1986).

MDS can identify major terrestrial-marginal marine gradients along the first and second axes, and seems to be least vulnerable to distortion from high beta diversity, non-normality, and non-linearity (Kovach, 1989). In this study, MDS analysis was performed on a subset of data from the original distribution range charts. Palynomorphs with high abundances and those with recognized paleoenvironmental significance were selected for this analysis.

Sequence stratigraphic analyses for each section involved the integration of palynofacies, palynomorph paleoecology, and lithological data. They were combined to identify major depositional environments for the three sections. Key surfaces, (maximum flooding surfaces, sequence boundaries, and transgressive surfaces) were identified based on the stacking patterns of interpreted sedimentary environments. Then, systems tracts and sequences were recognized. Because of the limited number of proposed sections, this study was not intended to reconstruct a regional geometry for study areas. Rather, the main goal in proposing a sequence stratigraphic study was to provide a hierarchical framework of depositional environments, that could be used to recognize major relative sea level changes during the time interval studied. Sequence stratigraphy terminology and techniques followed that of Van Wagoner *et al.* (1990).

The suggestion by Rosenzweig (1995) of using the word "diversity" in its original meaning of denoting number of species (called richness in the literature) is followed in the analysis of pollen/spores diversity. Patterns of pollen and spores diversity were analyzed using several methods: Rarefaction, a method used to compare the diversity of different samples taking into account sampling density (Raup, 1975). Small number of species in a sample can be an artifact of the number of grains counted in the sample. Rarefaction is a method that addresses this problem. It is an interpolation technique

making it possible to estimate how many species would have been found had the sample been smaller than it actually was (Raup, 1975). In this form, diversity from small and large samples can be compared with each other. Rarefaction has several limitations: collections to be compared should be taxonomically similar, they must also be obtained by using standardized sampling and analytic procedures, they should derive from similar habitats (all from similar lithologies when possible), and rarefaction must be restricted to interpolation of values not greater than the number of individuals of the parent collection (Tipper, 1979). The hypothesis under test is that rarefaction curves being compared refer to collections drawn from same population (population of diversities, not species); the alternative hypothesis is that the populations differ in their diversities (Tipper, 1979). Two populations composed of different species, then, could have similar rarefaction curves indicating that their diversities are similar. Rarefaction curves were calculated with the Rarefaction calculator developed by C. Krebs and J. Brzustowski (http://www.biology.ualberta.ca/jbrzusto/rarefact.html #Top) using the Hurlbert formulae to calculate number of species and Simberloff formulae to calculate the variance.

Bootstrap was used to determine the average of number of species/sample for Paleocene and Eocene strata regardless the number of observed samples. Bootstrapping constructs estimates of frequency distributions for use in conducting statistical tests (Gilinsky, 1991). The mean diversity was calculated for a number of samples randomly selected with replacement from two datasets: seven samples from the Paleocene and 13 from the Eocene. This procedure was repeated 4999 times, and then average and confidence intervals for each time interval were calculated and compared. This analysis was done in MetaWin 1.0 with the help of Ricardo Holdo (University of Florida).

The range-through method (Boltovskoy, 1988) was used to estimate standing diversity. This method assumed that a taxon is present in a sample if the taxon is present in samples below and above the sample examined. This method takes into account facies-related fossils and differences in capture probability for each taxon. The method

underestimates diversity for intervals at the beginning and end of a section, since there are not more samples that allow to extend ranges of rarer species (Boltovskoy, 1988).

The overall floral similarity throughout the section was observed using detrended correspondence analysis (DCA) developed by Hill and Gauch (1980). The ordination was performed on the presence-absence data that already had range-through extensions. Samples with less than 20 grains were eliminated from analysis. DCA summarizes variation in the composition of the assemblages in a small number of dimensions (Wing, 1998). This method assumed that cases come from a gradient in which different variables (in this case taxa) characterize different parts of the gradient making it particularly well suited for distinguishing single, major gradients in the first axis (Kovach, 1989). DCA analysis were performed in MVSP 3.0 statistical software developed by Warren Kovach (http://www.kovcomp.co.uk/mvsp/).

The unbiased Simpson index ($SI=\sum(ni(ni-1)/N(N-1))$, N=number of individuals in sample, ni=number of individuals of species i in the sample) was calculated to estimate underlying diversity independently of sample size (Rosenzweig, 1995). This index is free from influence of size of sample, it is adequate to estimate diversity of small samples, and when used as -Ln(SI) it increases as the number of species does (Rosenzweig, 1995). This index was calculated using MVSP 3.0 statistical software. Palynomorphs other than pollen and spores were excluded from all the analysis.

CHAPTER 4
REGIONAL GEOLOGICAL SETTING

Colombian geology has been complicated by uplift attributed to the Andean orogeny that began during the late Cretaceous and was most active during the Pliocene (Van der Hammen *et al.*, 1973). In general, sedimentary rocks comprise 70% of all the rocks in Colombia. Forty percent of the outcropping sedimentary strata are Cretaceous, approximately 55% are Tertiary and Quaternary, while 5% are Paleozoic, Triassic and Jurassic (Etayo-Serna *et al.*, 1983). The sedimentary rocks can be found in ten tectono-stratigraphic provinces (Etayo-Serna *et al.*, 1983) that can be seen in Figures 3-1 and 4-1. Paleozoic sedimentary and metamorphic rocks, Triassic red beds and marine limestones, and Jurassic tuffs constitute the basement onto which Cretaceous rocks onlapped (Cediel *et al.*, 1981). The late Jurassic-Cretaceous sea first inundated the northwestern Andean Basin possibly through a western corridor situated in the area that is now Central Colombia at the latitude of Bogotá during the Titonian-Berriasian. Subsequently this sea extended into most of southern and northern Colombia (Etayo-Serna *et al.*, 1976). Cretaceous facies have been interpreted as representing marine environments of deposition, especially during the Turonian to Campanian interval (Etayo-Serna, 1979; Barrio and Coffield, 1992). Tertiary rocks accumulated in alluvial plain to littoral environments (Etayo-Serna *et al.*, 1983) with the exception of the marine strata of the Atrato Basin and Lower Magdalena Valley (Galvis, 1980; Duque Caro, 1990). Colombia has undergone a complex history of compressional tectonic events that have produced a mix of superimposed structures (Dengo and Covey, 1993). The Eastern Cordillera (Figs. 3-1 and 4-1) was uplifted throughout the Tertiary with a late intense pulse during the Pliocene-Pleistocene (Van der Hammen *et al.*, 1973), and is bounded by

thrust faults systems on its eastern and western margins. Eastern faults dip westward (Guaicaramo thrust system) and western faults dip eastward (Honda-Bituima thrust system), thus structurally creating a large "pop-up" feature that uplifted the Eastern Cordillera (Irving, 1975).

Colombian stratigraphic nomenclature has been complicated by the fact that several authors and oil companies have used different names for the same lithostratigraphic units, or the same name for different lithostratigraphic units (Montes *et al.*, 1993). A recompilation of published information (Montes *et al.*, 1993) has revealed that the lack of field data and the disorder in stratigraphic nomenclature have resulted in weak tectono-stratigraphic interpretations. These inconsistencies have made regional interpretations inaccurate or suspect when based on the literature. In this study, the stratigraphical nomenclature proposed by the Colombian Stratigraphical Lexicon (Porta, 1974) is followed.

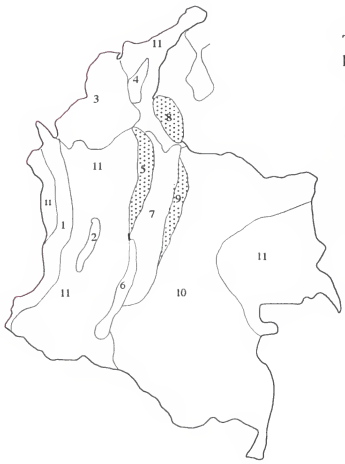


Figure 4-1. Sedimentary tectono-stratigraphic provinces of Colombia. The sections studied are in terranes 5, 8, and 9 indicated by dotted pattern (After Etayo-Serna, 1983).

CHAPTER 5
BIOSTRATIGRAPHY

Biostratigraphy is a very important for understanding Colombian geology because rocks are rarely well exposed, and structural geology is very complex due to the interaction of the Caribbean, South America and Nazca plates during the last 150 million years. Rapid and dramatic facies and thickness changes across faults are frequent, and correlation of formations requires an excellent biostratigraphic control.

The most important, and very often the only, biostratigraphic tools in Tertiary sediments in the majority of Colombia are palynomorphs (mainly pollen and spores). Intense palynological work, mostly related to oil and coal exploration, has been done for the past 35 years. Unfortunately, not much work has been published especially for Paleogene sediments.

One of the fundamental elements for producing a detailed biostratigraphic framework is a comprehensive understanding of pollen and spores taxonomy. A large percentage (~50%) of morphotypes described for Paleogene of Northern South America (see Table 5-1) lack detailed descriptions and good photographic records. In order to solve this problem, I visited the most important palynological collections of neotropical fossil pollen and spores that are available and still store some Paleogene holotypes (Petrobras in Rio de Janeiro, Pedevesa in Caracas, and University of Amsterdam in Amsterdam). Other collections, such as the one containing the 45 holotypes of Gonzalez (1967), were damaged and no longer useful (E. Gonzalez, personal communication). Others could not be found and possibly are already spoiled (most of Van der Hammen's holotypes of his 1955 to 1966 papers), and others are not available to the public or are not curated (Sarmiento, 1992).

In the Appendix A I present a detailed taxonomic analysis of 300 pollen, spores, and dinoflagellate species, that will be used in the biostratigraphic analysis.

Biostratigraphic ranges were analyzed using graphic correlation (see Chapter 3 for a more detailed description of this method). This approach is especially useful with pollen and spores because it allows an objective analysis of taxon range distributions. Phytogeography, especially in tropical regions where many species tend to have restricted ranges, would affect the use of traditional biostratigraphic zones. For example, there is a zone named *Spinizonocolpites baculatus*, defined by Muller *et al.* (1987) for the lower Paleocene of northern South America. The base of this zone is defined by the first occurrence of *S. baculatus* and the top by the last occurrence of *S. baculatus*. However, *S. baculatus* has long been recognized as related to *Nypa*, an extant mangrove palm living in South East Asia (Germeraad *et al.*, 1968); therefore, *S. baculatus* would be restricted to lower coastal plain and estuarine facies. Fluvial sediments accumulated during the lower Paleocene would be unlikely to contain *S. baculatus*. Therefore, following the biostratigraphic zone approach, lower Paleocene strata would be "lacking" in fluvial sections because the pollen zone is absent, and an unconformity would be postulated. Probably, many of the "unconformities" that have been registered in Colombia strata (e.g., see Dengo and Covey, 1993) are an artifact of plant biogeography rather than time gaps. Graphic correlation approach accounts for facies changes and does not assume *a priori* that a particular taxon is a marker for any time interval. It also allows to use whole assemblages rather than "index" taxa and test hypothesis on range distributions. Graphic correlation becomes more robust as more information of different sections is added into the analysis. Finally, graphic correlation is more objective and relies less on personal opinion as traditional biostratigraphic zonations do.

Previous Studies

As far as can be determined thirty-three papers have been published on the Paleogene palynology of northern South America including Colombia, Venezuela, Guyana, and Brazil (Van der Hammen, 1954; Kuyl *et al.*, 1955; Norem, 1955; Van der Hammen, 1956, 1957a,b, 1958; García, 1958; Paba-Silva and Van der Hammen, 1958; Sole de Porta, 1961a,b, 1963; Porta and Sole de Porta, 1962; Van der Hammen and Wymstra, 1964; Leidelmeyer, 1966; Van der Hammen and Garcia, 1966; Gonzalez, 1967; Germeraad *et al.*, 1968; Schuler and Doubinger, 1970; Sole de Porta, 1971; Wijmstra, 1971; Doubinger, 1973; Regali *et al.*, 1974; Doubinger, 1976; Dueñas, 1980; Muller *et al.*, 1987; Colmenares, 1988; Colmenares and Terán, 1990, 1993; Sarmiento, 1992; Guerrero and Sarmiento, 1996; Rull, 1997b, 1998)

All these papers, the majority of which were published before 1971, focused only on pollen and spores. Seventeen of them presented pollen/spores of Paleocene strata, five studies looked at Eocene strata, and five Oligocene strata. Only three of these studies provided measured stratigraphic sections with palynomorph range distributions. The publications listed above have yielded 339 taxa identified from Paleogene strata of northern South America including Brazil, Guiana, Venezuela, Peru, Ecuador and Colombia (Table 5-1). A comparison with living taxa have been attempted for just 55 of them. This information is summarized in Table 5-2, and Figure 5-1.

Several zonation schemes based on pollen and spores have been proposed for the Paleocene-Eocene of northern South America (Van der Hammen, 1957a, b; Leidelmeyer, 1966; Gonzalez, 1967; Germeraad *et al.*, 1968; Regali *et al.*, 1974; Muller *et al.*, 1987). However, only two (Germeraad *et al.*, 1968; Regali *et al.*, 1974) offered some independent justification for the proposed age assignments.

Van der Hammen (1957 a, b; 1958) and his Holland school (Leidelmeyer, 1966; Gonzalez, 1967) were the precursors of palynological studies of Tertiary strata in northern South America. They used pollen/spores fluctuations (a pollen diagram) as a

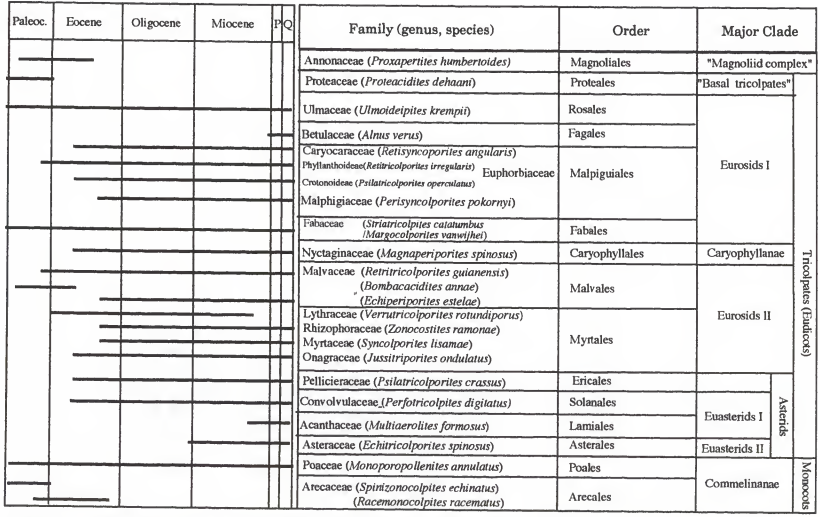


Figure 5-1. Range chart for selected angiosperm fossil pollen in northern South America (modified from Muller, 1981, suprageneric classification after APG, 1998 and Judd *et al.*, 1999)

Table 5-1. Pollen and spores named from the Paleogene of northern South America

taxa	Author
Anacolosidites luteoides	Cookson and Pike, 1954
Annutriporites iversenni	(Van der Hammen, 1954) Gonzalez, 1967
Arcotriporites asteroides	Gonzalez, 1967
Baculamonocolpites multispinosus	(Van der Hammen, 1954) Sole de Porta, 1971
Bacumorphomonocolpites tausae	Sole de Porta, 1971
Bacustephanocolpites stereos	Gonzalez, 1967
Bombacacidites annae	(Van der Hammen, 1954) Germeraad *et al.* , 1968
Bombacacidites brevis	(Duenas, 1980) Muller *et al.* , 1987
Bombacacidites cililoensis	Muller *et al* ., 1987
Bombacacidites foveoreticulatus	Muller *et al* ., 1987
Bombacacidites soleformis	Muller *et al* ., 1987
Brevitricolpites variabilis	Gonzalez, 1967
Buttinia andreevi	Boltenhagen, 1967
Cicatricosisporites baculatus	Regali, Uesugui, and Santos, 1974
Cicatricosisporites cirae	Kedves and Sole de Porta, 1963
Cicatricosisporites colombiensis	Kedves and Sole de Porta, 1963
Cicatricosisporites cristatus	Regali, Uesugui, and Santos, 1974
Cicatricosisporites cundinamarcensis	Kedves and Sole de Porta, 1963
Cicatricosisporites dorogensis	(Potonie and Gelletich, 1933) Kedves, 1961
Cicatricosisporites radiatus	Krutzsch, 1959
Cicatricosisporites tabacensis	Kedves and Sole de Porta, 1963
Clamonocolpites terrificus	Gonzalez, 1967
Classites capucinii	Gonzalez, 1967
Clavainaperturites cordatus	Gonzalez, 1967
Clavamonocolpites microclavatus	Muller *et al* ., 1987
Clavastephanoporites ambigens	Leidelmeyer, 1966
Clavatricolpites gracilis	Gonzalez, 1967
Clavatricolporites leticiae	Leidelmeyer, 1966
Clavatriletes disparilis	Regali, Uesugui, and Santos, 1974
Colombipollis tropicalis	Sarmiento, 1992
Crassiectoapertites columbianus	Duenas, 1980
Crassitricolporites brasiliensis	Herngreen, 1972
Crassitricolporites costatus	Sarmiento, 1992
Cricotriporites fragilis	Van Hoeken-Klinkenberg, 1966
Cricotriporites guianensis	Leidelmeyer, 1966
Cricotriporites operculatus	Van Hoeken-Klinkenberg, 1966
Cristatricolpites analemae	Leidelmeyer, 1966
Crototricolpites americanus	Wijmstra, 1971
Crototricolpites annemarie	Leidelmeyer, 1966
Crusafontites grandiosus	Sole de Porta, 1971
Ctenilliphonidites costatus	(Van Hoeken-Klinkenberg, 1964) Van Hoeken-Klinkenberg, 1966
Ctenolophonidites lisamae	(Van der Hammen and Garcia, 1966) Germeraad *et al.* , 1968
Curvimonocolpites inornatus	Leidelmeyer, 1966
Cyclusphaera euribei	Elsik, 1966
Divisisporites enormus	Pfug, 1953
Duplotriporites ariani	Sarmiento, 1992
Echimonocolpites coni	Sarmiento, 1992
Echimonocolpites densus	Gonzalez, 1967
Echimonocolpites protofranciscoi	Sarmiento, 1992
Echimonocopites ruedae	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966
Echimorphomonocolpites gracilis	Gonzalez, 1967
Echimorphomonocolpites solitarius	Gonzalez, 1967
Echinatisporis minutis	Van der Kaars, 1983
Echinoidites problematicus	Gonzalez, 1967
Echiperiporites akanthos	Van der Hammen and Wymstra, 1964
Echiperiporites estelae	Germeraad, Hopping, and Muller, 1968

Table 5-1--continued.

taxa	author
Echistephanoporites alfonsi	Leidelmeyer, 1966
Echitricolpites communis	Regali, Uesugui, and Santos, 1974
Echitricolpites polaris	Regali, Uesugui, and Santos, 1974
Echitriletes muelleri	Regali, Uesugui, and Santos, 1974
Echitriporites guianensis	Leidelmeyer, 1966
Echitriporites nuriae	Duenas, 1980
Echitriporites triangulíformis	Van Hoeken-Klinkenberg, 1964
Ephedripites multicostatum	Brenner, 1963
Ephedripites vanegensis	Van der Hammen and Garcia, 1966
Ericipites annulatus	Gonzalez, 1967
Filtotriletes nigeriensis	Van Hoeken-Klinkenberg, 1966
Foveodiporites guianensis	Wijmstra, 1971
Foveodiporites operculatus	Van der Kaars, 1983
Foveostephanocolpites perfectus	Leidelmeyer, 1966
Foveostephanocolpites typicus	Leidelmeyer, 1966
Foveostephanocolporites liracostatus	Leidelmeyer, 1966
Foveotricolpites genuinus	Gonzalez, 1967
Foveotricolpites perforatus	Van der Hammen and Garcia, 1966
Foveotricolpites pomarius	Van der Hammen and Garcia, 1966
Foveotricolpites santanderianus	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966
Foveotricolporites caldensis	Gonzalez, 1967
Foveotricolporites crasiexinus	Van Hoeken-Klinkenberg, 1966
Foveotricolporites marginatus	Gonzalez, 1967
Foveotricolporites voluminosus	Gonzalez, 1967
Foveotriletes margaritae	(Van der Hammen, 1954) Germeraad, Hopping, and Muller, 1968
Foveotriporites hammenii	Gonzalez, 1967
Gemmamonocolpites amicus	Gonzalez, 1967
Gemmamonocolpites barbatus	Gonzalez, 1967
Gemmamonocolpites dispersus	Sarmiento, 1992
Gemmamonocolpites gemmatus	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966
Gemmamonocolpites macrogemmatus	Muller, Giacomo, and Erve, 1987
Gemmamonocolpites ovatus	Gonzalez, 1967
Gemmastephanocolpites asteroformis	Leidelmeyer, 1966
Gemmastephanocolpites gemmatus	Van der Hammen and Garcia, 1966
Gemmastephanoporites breviculus	Gonzalez, 1967
Gemmastephanoporites polymorphus	Gonzalez, 1967
Gemmatricolpites pulcher	Gonzalez, 1967
Gemmatricolpites vigdisae	Leidelmeyer, 1966
Gemmatricolporites berbicensis	Leidelmeyer, 1966
Gemmatricolporites divaricatus	Leidelmeyer, 1966
Hamulatisporites caperatus	(Van Hoeken-Klinkenberg 1964) Schrank, 1994
Heterocolpites paleocenica	Van der Hammen and Garcia, 1966
Heterocolpites paluster	Gonzalez, 1967
Inaperturopollenites cursis	Sarmiento, 1992
Incertiscabrites pachoni	(Van der Hammen, 1954) Sarmiento, 1992
Incerturugulites carbonensis	Sarmiento, 1992
Jandufouria seamrogiformis	Germeraad, Hopping, and Muller, 1968
Janmulleripollis pentaradiatus	Di Giacomo and Van Erve, 1987
Jussitriporites undulatus	Gonzalez, 1967
Laevigatosporites catanejensis	Muller, Giacomo, and Erve, 1987
Leiotriletes guadensis	(Van Der Hammen, 1954) Sole de Porta, 1971
Longapertites brasiliensis	Gonzalez, 1967
Longapertites circularis	Gonzalez, 1967
Longapertites fossuloides	Gonzalez, 1967
Longapertites perforatus	Gonzalez, 1967
Longapertites perforatus	Sarmiento, 1992

Table 5-1--continued.

taxa	author
L. proxapertitoides var proxapertitoides	Van der Hammen and Garcia, 1966
L. proxapertitoides var reticulatus	Van der Hammen and Garcia, 1966
L. proxapertitoides var. reticuloides	Gonzalez, 1967
Longapertites vaneendenburgi	Germeraad, Hopping, and Muller, 1968
Longitrichotomocolpites triangularis	Gonzalez, 1967
Magnaperiporites spinosus	Gonzalez, 1967
Magnastriatites grandiosus	(Kedves and Sole de Porta, 1963) Duenas 1980
Magnatriporites abstractus	Gonzalez, 1967
Magnotetradites magnus	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966
Margocolporites vanwijhei	Germeraad, Hopping, and Muller, 1968
Mauritiidites franciscoi var. franciscoi	(Van der Hammen, 1956) Van Hoeken-Klinkenberg, 1964
Mauritiidites franciscoi var. minutus	Van der Hammen and Garcia, 1966
M. franciscoi var. pahyexinatus	Van der Hammen and Garcia, 1966
Microfoveolatosporis skottsbergii	(Selling, 1946) Srivastava, 1971
Microfoveotriporites cretaceous	Van Hoeken-Klinkenberg, 1966
Momipites africanus	Van Hoeken-Klinkenberg, 1966
Monolites ferdinandi	(Van der Hammen, 1954) Sole de Porta, 1972
Monoporites annulatus	Van der Hammen, 1954
Monoporites annuloides	Gonzalez, 1967
Monoporites parcus	Sarmiento, 1992
Papillamonocolpites splendedus	Gonzalez, 1967
Papillopolis partialis	Gonzalez, 1967
Perfotricolpites digitatus	Gonzalez, 1967
Perfotricolpites semistriatus	Gonzalez, 1967
Periretipollis spinosus	Legoux, Belsky, and Jardine, 1972
Periretisyncolpites giganteus	Keiser and Du Chene, 1979
Perisyncolporites pokornyi	Germeraad, Hopping, and Muller, 1968
Plicapollis arcii	Gonzalez, 1967
Polotricolporites concretus	Gonzalez, 1967
Polotricolporites mocinnii	Gonzalez, 1967
Polotricolporites versabilis	Gonzalez, 1967
Polyadopollenites mariae	Duenas, 1980
Polypodiaceoisporites potonie	(Potonie and Gell, 1933) Kedves, 1961
Proteacidites dehaani	Germeraad, Hopping, and Muller, 1968
Proteacidites miniporatus	Van Hoeken-Klinkenberg, 1966
Protudiporites typicus	Van Hoeken-Klinkenberg, 1966
Proxapertites cursus	Van Hoeken-Klinkenberg, 1966
Proxapertites facetus	Regali, Uesugui, and Santos, 1974
Proxapertites humbertoides	(Van der Hammen, 1954) Sarmiento, 1992
Proxapertites magnus	Muller, Giacomo, and Erve, 1987
Proxapertites minutus	Duenas, 1980
Proxapertites operculatus	(Van der Hammen, 1954) Van der Hammen, 1956
Proxapertites psilatus	Sarmiento, 1992
Proxapertites tertiaria	Van der Hammen and Garcia, 1966
Proxapertites verrucatus	Sarmiento, 1992
Pseudostephanocolpites perfectus	Gonzalez, 1967
Pseudostephanocolpites? verdi	Gonzalez, 1967
Psilabrevitricolpites flexibilis	Van Hoeken-Klinkenberg, 1966
Psilabrevitricolpites rotundus	Van Hoeken-Klinkenberg, 1966
Psilabrevitricolporites annulatus	Sarmiento, 1992
Psilabrevitricolporites simpliformis	Van der Kaars, 1983
Psiladiporites redundantis	Gonzalez, 1967
Psilamonocolpites ciscudae	Sarmiento, 1992
Psilamonocolpites grandis	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966
Psilamonocolpites huertasi	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966
Psilamonocolpites medius	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966

Table 5-1--continued.

taxa	author
Psilastephanocolpites adinos	Gonzalez, 1967
Psilastephanocolpites globulus	Van der Kaars, 1983
Psilastephanocolpites maia	Leidelmeyer, 1966
Psilastephanocolpites marginatus	Gonzalez, 1967
Psilastephanocolpites verrucosus	Gonzalez, 1967
Psilastephanocolporites fissilis	Leidelmeyer, 1966
Psilastephanocolporites globulus	Van Hoeken-Klinkenberg, 1966
Psilastephanocolporites variabilis	Regali, Uesugui, and Santos, 1974
Psilastephanoporites caribiensis	Duenas, 1980
Psilastephanoporites stellatus	Regali, Uesugui, and Santos, 1974
Psilasyncolporites parvus	Gonzalez, 1967
Psilatephanocolpites regularis	Van Hoeken-Klinkenberg, 1966
Psilatricolpites acerbus	Gonzalez, 1967
Psilatricolpites brevis	Gonzalez, 1967
Psilatricolpites clarissimus	Van der Hammen and Wymstra, 1964
Psilatricolpites colpiconstrictus	Van Hoeken-Klinkenberg, 1966
Psilatricolpites microverrucatus	Sarmiento, 1992
Psilatricolpites minutus	Gonzalez, 1967
Psilatricolpites operculatus var. minutus	Gonzalez, 1967
Psilatricolpites palaeoceanica	Van der Hammen and Garcia, 1966
Psilatricolpites polaroides	Gonzalez, 1967
Psilatricolpites simplex	Gonzalez, 1967
Psilatricolpites solus	Leidelmeyer, 1966
Psilatricolpites undamarginis	Leidelmeyer, 1966
Psilatricolporites costatus	Duenas, 1980
Psilatricolporites crassus	Van der Hammen and Wymstra, 1964
Psilatricolporites maculosus	Regali, Uesugui, and Santos, 1974
Psilatricolporites marginatus	Van der Kaars, 1983
Psilatricolporites normalis	Gonzalez, 1967
Psilatricolporites obscurus	Gonzalez, 1967
Psilatricolporites operculatus	Van der Hammen and Wymstra, 1964
P. operculatus var. medius	Gonzalez, 1967
Psilatricolporites optimus	Gonzalez, 1967
Psilatricolporites pachyexinatus	Van der Kaars, 1983
Psilatricolporites transversalis	Duenas, 1980
Psilatricolporites triangularis	Van der Hammen and Wymstra, 1964
Psilatricolporites vanus	Gonzalez, 1967
Psilatriletes martinensis	Sarmiento, 1992
Racemonocolpites facilis	Gonzalez, 1967
Racemonocolpites racematus	(Van der Hammen, 1954) Gonzalez, 1967
Racemonocolpites racematus	Gonzalez, 1967
Racemonocolpites romanus	Gonzalez, 1967
Retibrevitricolpites catatumbus	Gonzalez, 1967
Retibrevitricolpites distinctus	Van Hoeken-Klinkenberg, 1966
Retibrevitricolpites increatus	Gonzalez, 1967
Retibrevitricolpites retibolus	Leidelmeyer, 1966
Retibrevitricolpites triangulatus	Van Hoeken-Klinkenberg, 1966
Retidiporites agilis	Gonzalez, 1967
Retidiporites botulus	Leidelmeyer, 1966
Retidiporites elongatus	Sarmiento, 1992
Retidiporites magdalenensis	Van der Hammen and Garcia, 1966
Retiheterocolpites tertiarus	Gonzalez, 1967
Retimonocolpites bernardii	Gonzalez, 1967
Retimonocolpites claris	Sarmiento, 1992
Retimonocolpites longapertitoides	Sarmiento, 1992
Retimonocolpites microreticulatus	Van der Hammen and Garcia, 1966

Table 5-1--continued.

taxa	author
Retimonocolpites splendidus	Gonzalez, 1967
Retimonocolpites tertiarius	Gonzalez, 1967
Retipollenites confusus	Gonzalez, 1967
Retistephanocolpites angeli	Leidelmeyer, 1966
Retistephanocolpites finalis	Gonzalez, 1967
Retistephanocolpites minutus	Gonzalez, 1967
Retistephanocolpites regularis	Van Hoeken-Klinkenberg, 1966
Retistephanocolpites tropicalis	Duenas, 1980
Retistephanocolpites williamsi	Germeraad, Hopping, and Muller, 1968
Retistephanocolporites festivus	Gonzalez, 1967
Retistephanoporites angelicus	Gonzalez, 1967
Retisyncolporites angularis	Gonzalez, 1967
Retisyncolporites aureus	Gonzalez, 1967
Retitricolpites absolutus	Gonzalez, 1967
Retitricolpites adeptus	Gonzalez, 1967
Retitricolpites adultus	Gonzalez, 1967
Retitricolpites agricaulis	Leidelmeyer, 1966
Retitricolpites amapaensis	Regali, Uesugui, and Santos, 1974
Retitricolpites antonii	Gonzalez, 1967
Retitricolpites bonus	Gonzalez, 1967
Retitricolpites brevicolpatus	Sarmiento, 1992
Retitricolpites cecryphalium	Leidelmeyer, 1966
Retitricolpites clarensis	Gonzalez, 1967
Retitricolpites colombiae	(Van der Hammen, 1954) Sarmiento, 1992
Retitricolpites conciliatus	Gonzalez, 1967
Retitricolpites constrictus	Gonzalez, 1967
Retitricolpites florentinus	Gonzalez, 1967
Retitricolpites herrerae	(Van der Hammen, 1954) Van der Hammen and Garcia, 1966
Retitricolpites incisus	Gonzalez, 1967
Retitricolpites josephinae	(Van der Hammen, 1954) Sarmiento, 1992
Retitricolpites kwakwanensis	Leidelmeyer, 1966
Retitricolpites magnus	Gonzalez, 1967
Retitricolpites maledictus	Gonzalez, 1967
Retitricolpites marginatus	Van Hoeken-Klinkenberg, 1966
Retitricolpites maturus	Gonzalez, 1967
Retitricolpites microreticulatus	(Van der Hammen, 1954) Van der Hammen and Wymstra, 1964
Retitricolpites minutus	Gonzalez, 1967
Retitricolpites minutus	Pierce, 1961
Retitricolpites obtusus	Van Hoeken-Klinkenberg, 1966
Retitricolpites ovalis	Van der Hammen and Wymstra, 1964
Retitricolpites perditus	Gonzalez, 1967
Retitricolpites perforatus	Gonzalez, 1967
Retitricolpites retiaphelis	Leidelmeyer. 1966
Retitricolpites reticulatus	(Van der Hammen, 1954) Van der Hammen and Wymstra, 1964
Retitricolpites saturum	Gonzalez, 1967
Retitricolpites simplex	Gonzalez, 1967
Retitricolporites amazonensis	Regali, Uesugui, and Santos, 1974
Retitricolporites cienaguensis	Duenas, 1980
Retitricolporites costatus	Leidelmeyer, 1966
Retitricolporites craceus	Gonzalez, 1967
Retitricolporites crassicostatus	Van der Hammen and Wymstra, 1964
Retitricolporites crassicostatus	Van Hoeken-Klinkenberg, 1966
Retitricolporites ellipticus	Van Hoeken-Klinkenberg, 1966
Retitricolporites equatoriales	Gonzalez, 1967
Retitricolporites exinamplius	Sarmiento, 1992
Retitricolporites finitus	Gonzalez, 1967

Table 5-1--continued.

taxa	author
Retitricolporites irregularis	Van der Hammen and Wymstra, 1964
Retitricolporites marianis	Gonzalez, 1967
Retitricolporites mariposus	Leidelmeyer, 1966
Retitricolporites medius	Gonzalez, 1967
Retitricolporites perpusillus	Regali, Uesugui, and Santos, 1974
Retitricolporites profundus	Gonzalez, 1967
Retitricolporites quadrosis	Regali, Uesugui, and Santos, 1974
Retitricolporites saskiae	Gonzalez, 1967
Retitricolporites squarrosus	Van der Hammen and Wymstra, 1964
Retitriporites dubiosus	Gonzalez, 1967
Retitriporites federicii	Gonzalez, 1967
Retitriporites simplex	Van der Kaars, 1983
Retitriporites tilburgii	Gonzalez, 1967
Retitriporites typicus	Gonzalez, 1967
Rugotricolpites oblatus	Sarmiento, 1992
Rugotricolporites felix	Gonzalez, 1967
Scabraperiporites asymmetricus	Duenas, 1980
Scabraperiporites nativensis	Regali, Uesugui, and Santos, 1974
Scabrastephanocolpites guaduensis	(Van der Hammen, 1954) Sarmiento, 1992
Scabrastephanocolpites scabratus	Van der Hammen and Garcia, 1966
Scabrastephanocolpites vanegensis	Van der Hammen and Garcia, 1966
Scabratricolpites angelicus	Sarmiento, 1992
Scabratricolpites thomasi	Sarmiento, 1992
Scabratricolpites tibialis	Gonzalez, 1967
Scabratricolporites platanensis	Duenas, 1980
Scabratriletes globulatus	Sarmiento, 1992
Scabratriporites moderatus	Gonzalez, 1967
Scabratriporites redundans	Gonzalez, 1967
Scabratriporites simpliformis	Van Hoeken-Klinkenberg, 1966
Semitectotriporites gratus	Gonzalez, 1967
Spinozonocolpites baculatus	Muller, 1968
Spinozonocolpites echinatus	Muller, 1968
Spinozonocolpites intrarugulatus	Muller, Giacomo, and Erve, 1987
Spinozonocolpites sutae	Sarmiento, 1992
Spironsyncolpites spiralis	Gonzalez, 1967
Spirosyncolpites clavatus	Gonzalez, 1967
Stephanocolpites costatus	Van der Hammen, 1954
Striatricolpites catatumbus	Gonzalez, 1967
Striatricolpites minor	Wijmstra, 1971
Striatricolpites semistriatus	Gonzalez, 1967
Striatricolporites agustinus	Gonzalez, 1967
Striatricolporites meleneae	Duenas, 1980
Striatricolporites pimulis	Leidelmeyer, 1966
Striatricolporites tenuissimus	Duenas, 1980
Striatriporites nigeriensis	Van Hoeken-Klinkenberg, 1966
Syncolporites lisamae	Van der Hammen, 1954
Syncolporites marginatus	Van Hoeken-Klinkenberg, 1964
Syncolporites poricostatus	Van Hoeken-Klinkenberg, 1966
Syncolporites rugucostatus	Sarmiento, 1992
Syndemicolpites tipicus	Van Hoeken-Klinkenberg, 1964
Tetradites umirensis	Van der Hammen, 1954
Tricolpites rubini	Van der Hammen, 1954
Ulmoideipites krempii	(Anderson, 1960) Elsik, 1968b
Venezuelites globoannulatus	Muller, Giacomo, and Erve, 1987
Verrucatosporites usmensis	(Van der Hammen, 1956) Germeraad *et al.* , 1968
Verrustephanocolpites verrucatus	Van der Hammen and Garcia, 1966

Table 5-1--continued.

taxa	author
Verrutricolpites isolatus	Leidelmeyer, 1966
Verrutricolpites unicus	Gonzalez, 1967
Verrutricolpites verrubolus	Leidelmeyer, 1966
Verrutricolporites haplites	Gonzalez, 1967
Verrutricolporites rotundiporis	Van der Hammen and Wymstra, 1964
Verrutriporites asymmetricus	Regali, Uesugui, and Santos, 1974
Wilsonipites margocolpatus	Muller, Giacomo, and Erve, 1987
Zlivisporis blanensis	Pacltova, 1961
Zonocostites duquensis	Duenas, 1980
Zonocostites ramonae	Germeraad, Hopping, and Muller, 1968
Zonotricolpites lineaus	Sarmiento, 1992
Zonotricolpites variabilis	Sarmiento, 1992

Table 5-2. Botanical affinities for fossil sporomorphs from northern South America (After Van der Hammen 1954, 1956, 1957a,b; Sole de Porta, 1961a, b; Van der Hammen and Garcia, 1966; Gonzalez, 1967; Germeraad *et al* ., 1968; Muller *et al.* , 1987; Sarmiento, 1992). Dispersion centers after Gentry (1982), suprageneric classification after Judd *et al* . (1999)

FOSSIL SPOROMORPH	PROBABLE BOTANICAL AFFINITY	FAMILY	FAMILY DISPERSION CENTER*
Alnipollenites verus	*Alnus*	Betulaceae	L
Anacolosidites luteoides	*Anacolosa* *Cathedra* *Ptychopetalum*	Olacaceae	AZ
Bombacacidites annae	*Bombax ceiba* *B. rhodognaphalon* *B. pubescens*	Bombacaceae	AZ
Buttinia andreevi	*Unknown*		
Cicatricosisporites dorogensis	*Anemia* *Mohria*	Schizaeaceae	
Crassoretitriletes vanraadshooveni	*Lygodium microphyllum*	Schizaeaceae	
Ctenolophonidites costatus	*Ctenolophon engleri*	Ctenolophonaceae	
Ctenolophonidites lisamae	*Ctenolophon*	Ctenolophonaceae	
Echiperiporites estelae	*Thespesia populnea* *Hibiscus tiliaceus* *Hibiscus rosa-sinensis* *Ipomoea phillomega*	Malvaceae Convolvulaceae	? AZ
Echitricolporites minutus	*Ambrosia* *Crassocephalum* *Iva* *Xanthium*	Compositae	AN
Echitricolporites spinosus	*Espeletia* *Mikania* *Pectis* *Wedelia* *Wulfia*	Compositae	AN
Echitriporites trianguliformis	*Embothrium* *Garnieria* *Persoonia* *Telopea*	Proteaceae	SA
Florschuetzia trilobata *F. levipoli* *F. semilobata*	*Lagerstroemia flos-regina* *Sonneratia alba*	Lythraceae	
Fenestrites spinosus	*Elephantopus angustifolia* *Rolandia fruticosa* *Vernonia canescens* *Vernonia remotiflora*	Compositae	AN
Foveotricolpites perforatus	*Extinct*		
Foveotriletes margaritae	*Lindsaya orbiculata* *Ophioglossum falcatum* *O. concinnuum*		

Table 5-2--continued.

FOSSIL SPOROMORPH	PROBABLE BOTANICAL AFFINITY	FAMILY	FAMILY DISPERSION CENTER*
Grimsdalea magnaclavata	*Palm type*	Palmae	AZ
Heterocolpites paluster		Melastomataceae	AN
Jandufouria seamrogiformis	*Catostemma*	Malvaceae	AZ
Jussitriporites undulatus		Onagraceae	SA
Longapertites perforatus		Annonaceae	AZ
Longapertites brasiliensis		Annonaceae	AZ
Magnastriatites grandiosus	*Ceratopteris (fresh-water)*	Parkeriaceae	
Magnaperiporites spinosus	*Mirabilis*	Nyctaginaceae	
Margocolporites vanwijhei	*Caesalpinia* *Adipera* *Brasiletia* *Haematoxylon* *Mezoneuron* *Poincianella*	Fabaceae	
Mauritiidites franciscoi	*Mauritia*	Palmae	AZ
Monoporites anulatus		Poaceae	?
Multiareolites formosus	*Adhatoda* *Anisotus* *Baloperone* *Dianthera* *Jacobinia* *Justicia* *Kolobochilus* *Monechma* *Rungia*	Acanthaceae	AN
Multimarginites vanderhammeni	*Sanchezia klugii* *Trichanthera gigantea*	Acanthaceae	AN
Pachydermites diederixi	*Symphonia globulifera*	Guttiferae	AN
Perfotricolpites digitatus	*Merremia glabra* *M. umbellata* *Scaevola* *Valerianella stenocarpa*	Convolvulaceae Goodeniaceae Caprifoliacea	AZ ? L
Perisyncolporites pokornyi	*Brachypteris* *Bunchosia* *Hiraea grandifolia* *Mascagnia* *Stigmaphyllum* *Tetrapterys*	Malpighiaceae	AZ
Proteacidites dehaani	*Guevina avellana*	Proteaceae	SA
Proxapertites cursus	*Nypa related*		
Proxapertites operculatus	*Nypa related* *Astrocarium (sensu TVH)*	Palmae	AZ
Psiladiporites minimus	*Artocarpus* *Ficus* *Sorocea*	Moraceae	AZ

Table 5-2--continued.

FOSSIL SPOROMORPH	PROBABLE BOTANICAL AFFINITY	FAMILY	FAMILY DISPERSION CENTER*
Retibrevitricolpites triangulatus	*Extinct*		
Retidiporites magdalenensis	*Banksia collina* *Dryandra longifolia*	Proteaceae	SA
Retistephanocolpites williamsi	*Ctenolophon parfivolius*	Ctenolophonaceae	
Retisyncolporites angularis	*Caryocar*	Caryocaraceae	
Retitricolporites irregularis	*Amanoa oblongifolia* *Pseudolachnostylis glauca*	Euphorbiaceae	AZ
Retitricolporites saskiae *Retricolporites guianensis*	*?* *Firmiania colorata* *Hildegardia barteri* *Glossostemon bruguieri* *Pterocymbium beccari* *Sterculia mexicana* *Trichospermum*	Malvaceae Malvaceae	AZ
Spinozonocolpites baculatus *Spinozonocolpites echinatus*	*Nypa fruticans*	Palmae	AZ
Stephanocolpites costatus	*Tabernaemontana attenuata*	Apocynaceae	AZ
Striansyncolpites zwaardi	*Cuphea*	Lythraceae	L?
Striatricolpites catatumbus	*Crudia* *Anthonotha* *Isoberlinia* *Macrolobium bifilium*	Fabaceae sub. Faboideae	L
Striatricolporites agustinus		Anacardiaceae	AZ?
Syncolporites lisamae		Myrtaceae	
Verrucatosporites usmensis	*Stenochlaena palustris* *Phlebodium aureum* *Histiosperis incisa* *Polypodium pectinatum* *P. triseriale*	Polypodiaceae	
Verrutricolporites rotundiporis	*Crenea maritima*	Lythraceae	AZ
Zonocostites ramonae	*Rhizophora* *Bruguiera* *Ceriops* *Carallia*	Rhizophoraceae	AZ

* AZ: Amazon
AN: Andes
SA: Southern South America
L: Laurasia

proxy for climatic cycles that presumably have a chronostratigraphic value. This "pollen diagram" is based on coal samples from different areas in Colombia. Proportions of different elements such as *Psilamonocolpites* group, *Mauritiidites* group, *Psilatriletes* group, are then calculated and plotted along the stratigraphic sections. Abundance peaks of specific groups are assumed to represent vegetational changes due to regional climatic changes. Therefore, they assumed that these peaks have a chronostratigraphic value and can be used for correlation. The epochs and ages of the Tertiary are then positioned in the pollen diagram based on the changes of relative proportions of certain groups, assuming that climatic changes are correlated with epoch/age boundaries.

Van der Hammen (1958) correlates the base of each epoch to an arenite level. This biostratigraphic scheme is then used to date most of the Tertiary continental formations of Colombia and Guyana (Van der Hammen, 1957a, 1957b, 1958; Van der Hammen and Wymstra, 1964; Leidelmeyer, 1966; Gonzalez, 1967; Wijmstra, 1971). Many of those datings are still deeply rooted in Colombian stratigraphy and used for correlation and modeling purposes. However, there are many problems associated with this approach. First, there is a statistical artifact associated with Van der Hammen's pollen diagrams, which is called the "closed sum" (Moore *et al.*, 1991; Kovach and Batten, 1994). Percentages of each sporomorph group were calculated by counting 200-300 grains per sample, then, the results were normalized. This method, however, tends to produce artificial negative correlations, when a group (A) significantly increases its abundance in a sample, another group (B) automatically decreases its abundances, even though its real abundance did not change. Then, these negative correlations among Van der Hammen groups could be an artifact of normalization, and peaks of certain groups could be the product of a decrease in other groups. There is also the weak assumption that pollen production and dispersal is similar for all species and that all taxa have a regional distribution (Porta and Sole de Porta, 1962). Furthermore, coals, the main source of Van der Hammen's samples, generally have a unique and facies-restricted flora

that is unsuitable for biostratigraphic purposes (Traverse, 1988). Porta and Sole de Porta (1962) analyzed twenty-four samples in 12 stratigraphic meters of a Miocene section in Cundinamarca, and found that its pollen diagram could be easily correlated with zones A and B of a general pollen diagram for the Oligocene. This approach also does not use an independent data-set that can test the ages given by pollen groups, therefore circular reasoning is highly possible. In conclusion, correlation of "climatic cycles" deduced from the pollen record probably reflects similar ecological conditions rather than time lines, and should not be used as a tool for dating Tertiary rocks.

Germeraad *et al.* (1968) in a pioneer study proposed a number of palynological zones for tropical Tertiary sediments. The zones were based mainly on material from Nigeria, Venezuela, and Colombia. They used several planktonic foraminifera to correlate their palynological zones to the geologic time scale. The stratigraphic ranges of those foraminifera taxa are presented in Figure 5-2. Ranges are derived from Postuma (1971), Bolli and Saunders (1985), Tourmankine and Luterbache (1985) (T&L85), Bolli *et al.* (1994), and Robinson and Wright (1993). Taxa that are not in Figure 5-2, but were mentioned by Germeraad *et al.* (1968), correspond to those of local importance that are not commonly used for global correlation. The following are the palynological zones proposed by Germeraad and the foraminifera used to correlate them with the geologic time scale (unless actually cited, the publications in which the names first appeared are not listed in the References list). The list also include the geographic location where the foraminifera were recorded from:

1. *Retidiporites magdalenensis* zone Danian-Paleocene

Nigeria

lower part of zone: Danian

Globigerina compressa (now *Planorotalites compressa* (Plummer 1926) Tourmankine, and Luterbache 1985): upper P1b-top P3 (T&L85)

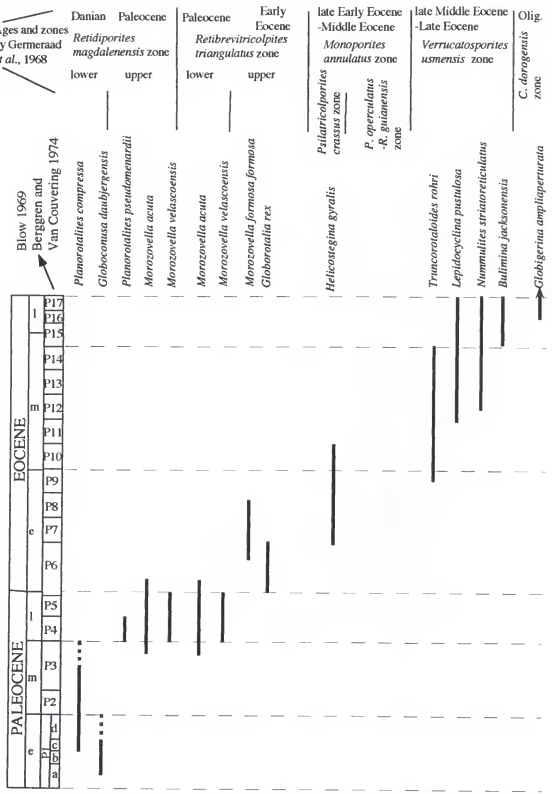


Figure 5-2. Chronostratigraphic ranges of foraminifera used to calibrate Germeraad *et al.* (1968) palynological zonation

G. daubjergensis (now *Globoconusa daubjergensis* (Bronnimann 1953) Toumarkine and Luterbacher 1985) middle P1a-top P1d (T&L85)

Nigeria

upper part of zone: Paleocene

Globorotalia pseudomenardii (now *Planorotalites pseudomenardii* (Bolli 1957) Toumarkine and Luterbacher 1985) base P4-top P4 (T&L85)

G. velascoensis (now *Morozovella velascoensis* (Cushman 1925) Toumarkine and Luterbacher 1985): base P4-lowest P6 (T&L85)

G. acuta (now *Morozovella acuta* (Toulmin 1941) Toumarkine and Luterbacher 1985): upper P3-~middle P6 (T&L85)

2. *Retibrevitricolpites triangulatus* zone Paleocene-early Eocene

Colombia

lower part of zone: Paleocene

Actinosiphon barbadensis

Nigeria

lower part of zone: Paleocene

Globorotalia velascoensis (now *Morozovella velascoensis* (Cushman 1925) Toumarkine and Luterbacher 1985): base P4-lowest P6 (T&L85)

G. acuta (now *Morozovella acuta* (Toulmin 1941) Toumarkine and Luterbacher 1985): upper P3-~middle P6 (T&L85)

Nigeria

upper part of zone: early Eocene

Globorotalia formosa (now *Morozovella formosa formosa* (Bolli 1957) Toumarkine and Luterbacher 1985): upper P6-upper P8 (T&L85)

Globorotalia rex Martin 1943: *G.rex* zone to lower part of *G. formosa/aragonensis* zone (Postuma, 1971). This is equivalent to P6 zone.

3. *Monoporites annulatus* zone late early Eocene-middle Eocene. This zone in the Caribbean is subdivided in the *Psilatricolporites crassus*, *Psilatricolporites operculatus*, and *Retritricolporites guianensis* zones.

Nigeria

lower, middle and upper part of zone: late early Eocene-middle Eocene

Cassigerinelloita amekiensis Stolk 1963

3a. *Psilatricolporites crassus* zone middle Eocene

Venezuela

lower part of zone: early middle Eocene

Linderina floridensis

Helicostegina gyralis Barker and Grimsdale, 1936: middle P6b/P9-middle P10/12, in lower part of Chapelton Formation Jamaica (Robinson and Wright, 1993). Authors probably refer to zones of Berggren and Miller (1988) that established Paleocene/ Eocene boundary in P6a/b boundary (P6a defined by LAD of *M. velascoensis*).

Lepidocyclina sp. A

Venezuela

upper part of zone: late middle Eocene

Helicolepidina spiralis form C in Van Raadshoven (1951). A larger foraminifera from Rio San Pedro fauna, Zulia, Venezuela. According to Van Raadshooven (1951), it occur in middle Eocene beds in Maracaibo area. Proposed age is based on co-occurrence with *Pseudophragmina (Proporocyclina)* cf. *perpusilla* (Vaughan), *Ferayina coralliformis*

Frizzell, and *Lepidocyclina* aff. *Lepidocyclina peruviana-r. douvillei* group, that are also larger foraminifera.

3b. *Psilatricolpites operculatus* and *Retitricolpites guianensis* zone late middle Eocene

Venezuela

Helicolepidina spiralis Tobler. A larger foraminifera from Rio San Pedro fauna, Zulia, Venezuela. According to Van Raadshooven (1951), it occurs in middle Eocene beds in Maracaibo area. Proposed age is based on co-occurrence with *Pseudophragmina* (*Proporocyclina*) cf. *perpusilla* (Vaughan), *Ferayina coralliformis* Frizzell, and *Lepidocyclina* aff. *Lepidocyclina peruviana-r. douvillei* group, that are also larger foraminifera.

4. *Verrucatosporites usmensis* zone late middle to late Eocene

Venezuela

lower part of zone: late middle Eocene

Helicolepidina spiralis Tobler. A larger foraminifera from Rio San Pedro fauna, Zulia, Venezuela. According to Van Raadshooven (1951), it occurs in middle Eocene beds in Maracaibo area. Proposed age is based on co-occurrence with *Pseudophragmina* (*Proporocyclina*) cf. *perpusilla* (Vaughan), *Ferayina coralliformis* Frizzell, and *Lepidocyclina* aff. *Lepidocyclina peruviana-r. douvillei* group, that are also larger foraminifera. Van Raadshooven (1951) also states that many species of larger foraminifera from Venezuela are new and difficult to correlated outside the Western Venezuelan basins.

Venezuela

upper part of zone: late Eocene

Lepidocyclina pustulosa H. Douville, 1917: base P12-top P17 (Robinson and Wright, 1993)

Pseudophragmina mirandana Hodson: a larger foraminifera from Rio San Pedro fauna, Zulia, Venezuela

Nummulites striatoreticulatus Rutten 1928: middle P12/P14 - top P17 (Robinson and Wright, 1993).

Helicostegina soldadensis Grimsdale: a larger foraminifera from Venezuela

Colombia

upper part of the zone: late Eocene

Bulimina jacksonensis Cushman 1925: late Eocene, in *Globigerinatheka semiinvoluta* and *Turborotalia cerroazulenzis* zones (Bolli *et al.*, 1994), base P15- top P17.

Nigeria

lower and upper part of zone: late middle Eocene-late Eocene

Chiloguembelina martini

Truncorotaloides rohri Bronnimann and Bermudez: middle P9-top P14 (T&L85).

5. *Cicatricosisporites dorogensis* zone Oligocene

Caribbean

Globigerina ampliaperturata middle P16 to P20, late late Eocene to early middle Oligocene (T&L85; Bolli and Saunders, 1985)

G. ciperoensis ciperoensis P20 to middle P22, middle to early late Oligocene (Bolli and Saunders, 1985)

Globorotalia opima opima P21, late middle Oligocene (Bolli and Saunders, 1985)

G. kugleri Bolli 1957, P22-N4, late Oligocene to early Miocene (Bolli and Saunders, 1985)

Nigeria

G. ciperoensis ciperoensis P20 to middle P22, middle to early late Oligocene (Bolli and Saunders, 1985)

G. ciperoensis angulisuturalis P21 to middle P22, late middle Oligocene to early late Oligocene (Bolli and Saunders, 1985)

G. kugleri Bolli 1957, P22-N4, late Oligocene to early Miocene (Bolli and Saunders, 1985)

In general, the age assignments of the Germeraad zones seems to be confirmed by the foraminifera (Fig. 5-2). However, the level of resolution is low compared to foraminiferal zones. The early and middle Eocene, and the Paleocene-Eocene boundary are very poorly resolved. Also, the lower boundary of the *Verrucatosporites usmensis* zone could be older than currently assumed (early? middle Eocene). The stratigraphic position of the foraminifera in relation with sporomorph ranges, however, was not presented in their paper with the exception of three sections in Nigeria. These three sections contain only planktonic zones P4 to P14 (Upper Paleocene to middle Eocene). It is difficult, then, to evaluate the calibration of the Germeraad zones especially for the middle and late Eocene.

Regali *et al.* (1974) also established several palynological zones for the Paleocene-Eocene of Brazil. The age for each zone is given by correlation with a planktonic foraminifera zonation for Brazil. Unfortunately they did not state what foraminifera taxa were used to calibrate the zonation, precluding an analysis of their data. However, it is evident a disparity in age assignments when compared with Germeraad *et al.* (1968) zones. For example the range of *Proxapertites cursus* is considered early Eocene, while it is Paleocene in Germeraad *et al.* (1968) scheme. When Germeraad *et al.* (1968) and Regali *et al.* (1974) zonations are compared (Fig. 5-3), it is evident a large discrepancy in the chronostratigraphic significance of many taxa. An 84% of the taxa

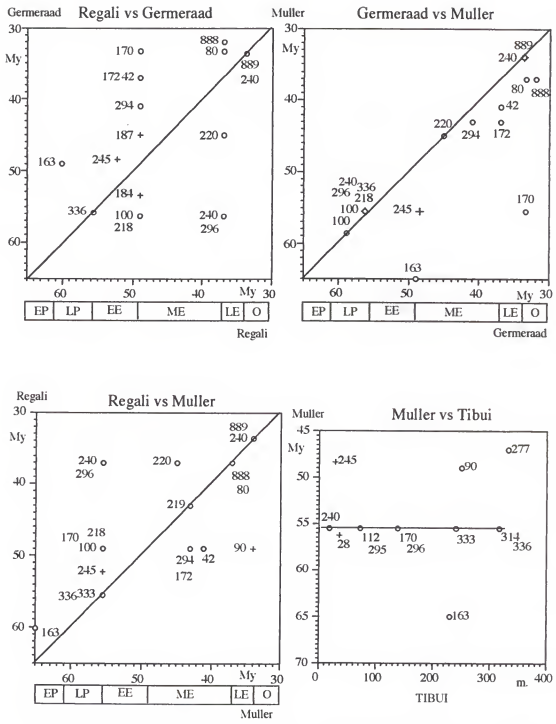


Figure 5-3. Comparison of Germeraad *et al.* (1968), Regali *et al.* (1974), and Muller *et al.* (1987) zonations. Name of taxa are in Table 5-6. Tibui section (Gonzalez, 1967) is compared against Muller's zonation suggesting a hiatus in the zonation. Circles=first appearance datums, Crosses=last appearance datums.

compared have discrepancies in the assumed chronostratigraphic value of first (FAD) and last appearance (LAD) datums (e.g., LAD of *Cicatricosisporites dorogensis* (#42), *Perisyncolporites pokornyi* (#172), *Perfotricolpites digitatus* (#170), etc.). A zonations is supposed to represent the absolute stratigraphic ranges of all taxa included. Here, evidently either both zonations are local in extent and/or they do not have the true range of most of the taxa involved.

Muller *et al.* (1987) established 11 palynological zones. Their work is mainly based on the Germeraad *et al.* (1968) zonation. Several modifications were done. The lower part of *V. usmensis* zone is considered middle Eocene, and the middle Eocene is subdivided into 6 zones. However, they did not provide independent data supporting the new age assignments as well as range charts of any of the sections analyzed. Colmenares and Terán (1993) and Sarmiento (1992) have challenged the regional application of these zones for western Venezuela, and central Colombia. Some of their zones could be ecological assemblages (Colmenares and Terán, 1993). A great discrepancy in biostratigraphic ranges and their chronostratigraphic significance is evident when comparing Muller with Germeraad and Regali's zonations (Fig. 5-3). Muller *et al.* (1987) and Germeraad *et al.* (1968) have a discrepancy of 47% in the range of the taxa compared (8 out of 17 taxa); while Muller vs. Regali have a discrepancy of 66% (12 out 18 taxa). Furthermore, the comparison of the sporomorph record of a section in the Catatumbo area (Gonzalez, 1967) with the Muller *et al.* (1974) zonation (Fig. 5-3) suggests a major hiatus in the zonation, casting serious doubts on the temporal and spatial significance of Muller zonation for the Eocene.

In summary, there is weak support and low resolution for age assignments of the palynological zones that have been proposed for the Paleocene-Eocene of northern South America. Subdivisions of the Eocene, and the exact paleontological and stratigraphical position of the Paleocene-Eocene boundary are still elusive.

Results

Using the graphic correlation technique (Shaw, 1964; Edwards, 1984; Edwards, 1989), a Composite Section (CS) was developed based on the stratigraphic distribution of pollen, spores, and dinoflagellate cysts of the three sections studied (see range charts in Tables 5-3 to 5-5) and the only two additional sections available from literature with palynomorph range charts and samples referenced to a stratigraphic position in a measured section (Tibui section in Catatumbo area after Germeraad *et al.*, 1968, and well T1 in Maracaibo Basin after Rull, 1997b). Eighty-four palynomorph taxa were selected to be used in the graphic correlation. This selection was based on common occurrence in all or most of the sections and a recognized chronostratigraphic potential based on experience of previous zonations (Germeraad *et al.*, 1968, Regali *et al.*, 1974, Muller *et al.*, 1987). First and last appearance datums (FAD and LAD respectively) for the five sections are summarized in Table 5-6. Also, abundance peaks of selected taxa (e.g., *Longapertites*) were included to evaluate their potential as a chronostratigraphic correlation tools. For Tibui section, 0 meters was assumed to be at the base of section in the Figure 3 of Gonzalez (1967). Gonzalez (1967) datums for *Cicatricosisporites dorogensis* and *Verrucatosporites usmensis* group were excluded from the analysis because he did not provide photographs of the grains and serious doubts have been made on Gonzalez' correct identification of these two taxa (Germeraad *et al.*, 1968). For T1 well (Rull, 1997b), 0 meters was considered at depth 2700 increasing upwell (Rull, 1997b, Fig. 3, p.82).

Five rounds of correlation were performed on the five stratigraphic sections in order to produce a Composite Section (a detailed explanation of graphic correlation procedure is given in Chapter 3). The two first rounds of correlation are shown in Figures 5-4, 5-5, 5-6, 5-7, 5-8, 5-9, and 5-10. The processes were repeated until ranges of each taxon stabilized. The first and last appearance datums of the taxa in

final Composite Section (CS) are shown in Table 5-7. Each of the sections was, then, correlated with the CS (Figs. 5-11 and 5-12).

The Composite Section (CS) was also compared with two sections of the Germeraad *et al.* (1968) work that had palynological range charts but lacked an exact stratigraphic position. Samples were identified instead with labels that do not correspond to stratigraphic position of the sample. However, the paper provided the thickness of each formation where the samples were taken. In order to use this information, I assumed that samples were equidistant across each particular formation. This probably will produce an indeterminate error in the correlation but it is preferred to not using the information at all, given the small amount of published information. Datums used for these two additional sections are shown in Table 5-8, and correlations in Figure 5-13. Datum information from these two sections was not included in the CS because the uncertainty in sample stratigraphic position.

The calibration of the CS against the international time table is a difficult task given the lack of published information on planktonic foraminifera and/or magnetostratigraphy in sections where palynological work has been done. Germeraad *et al.* (1968) mentioned a number of foraminifera associated with their zones (see the discussion in previous studies above). However, they only presented stratigraphic positions of both foraminifera and sporomorphs for three sections (one well and two outcrop sections), all of them from Nigeria. The two Nigerian outcrop sections (Imo and Ovim Bende) do not have a vertical scale, thickness of the formations, or depth of samples. In spite of this problem, the sections were used because they are some the few sections that have both planktonic foraminifera and pollen information. Thickness for each formation was assigned from the type sections for each formation, Imo Shale=~1300m, and Ameki=~900m (Nigeria, 1956), that are located near the place were sections were measured. Samples were then uniformly spread along each formation (datums used are shown in Table 5-8). A fourth section, Itori borehole, also is from

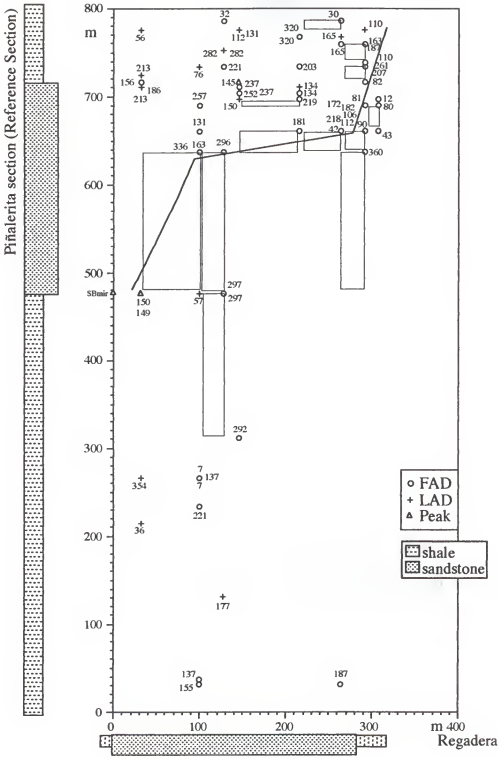


Figure 5-4. First round of correlation. Piñalerita (Reference Section) versus Regadera. SeeTable 5-6 for the names of the taxa used in graphic correlation. Boxes indicate strata down to next lower sample for first appearance datums (FAD) and up to next higher sample for last appearance datums (LAD) to take large gaps in sample interval into account.

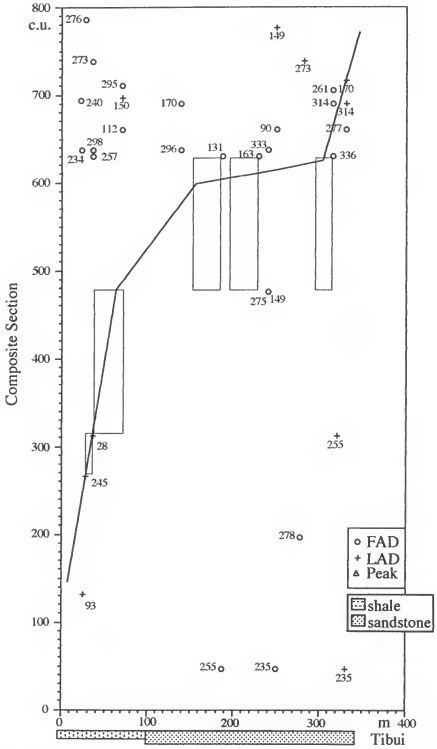


Figure 5-5. First round of correlation. Composite Section versus Tibui. Tibui section after Gonzalez (1967). See Table 5-6 for the names of the taxa used in graphic correlation. c.u.=composite units. Boxes indicate strata down to next lower sample for first appearance datums (FAD) and up to next higher sample for last appearance datums (LAD) to take large gaps in sample interval into account.

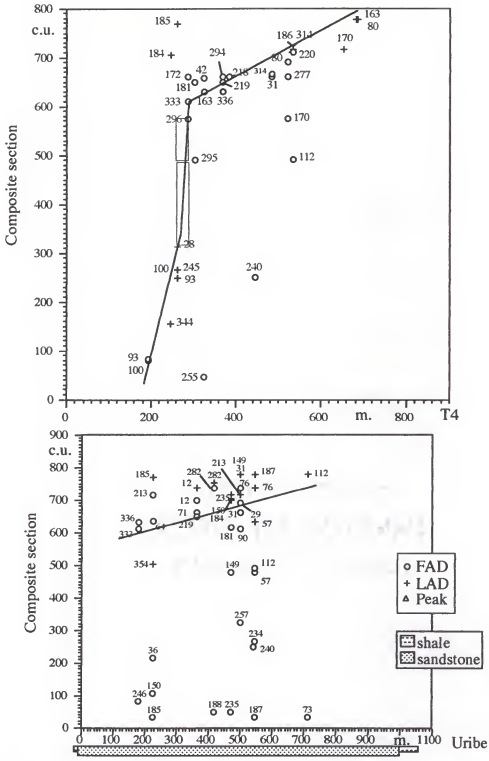


Figure 5-6. First round of correlation. Composite Section versus T4 and Uribe sections. T4 after Rull (1997b). See Table 5-6 for the names of the taxa used in graphic correlation. c.u.=composite units. Boxes indicate strata down to next lower sample for first appearance datums (FAD) and up to next higher sample for last appearance datums (LAD) to take large gaps in sample interval into account.

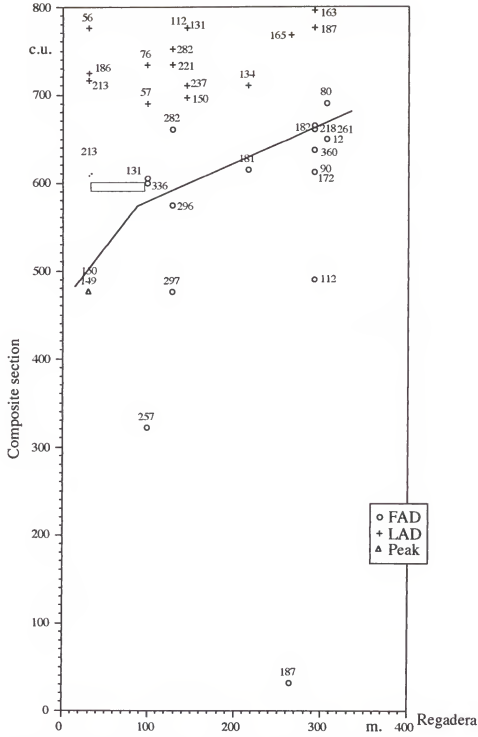


Figure 5-7. Second round of correlation. Composite Section versus Regadera. See Table 5-6 for the names of the taxa used in graphic correlation. c.u.=composite units. Datums of Composite Section derived from Regadera are excluded. Boxes indicate strata down to next lower sample for first appearance datums (FAD) and up to next higher sample for last appearance datums (LAD) to take large gaps in sample interval into account.

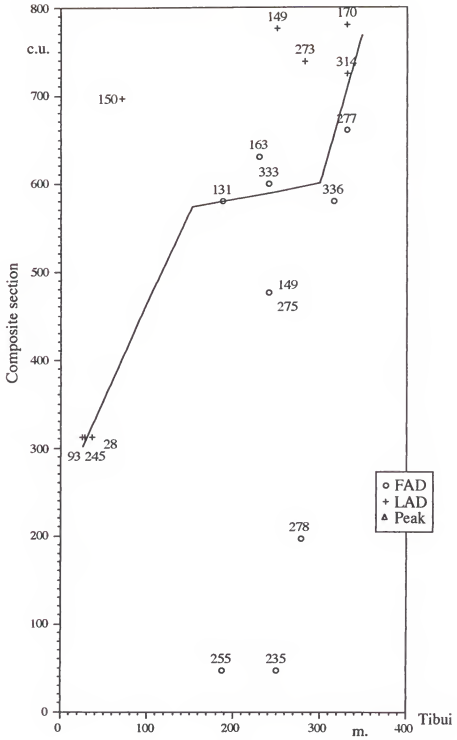


Figure 5-8. Second round of correlation. Composite Section versus Tibui. See Table 5-6 for the names of the taxa used in graphic correlation. c.u.=composite units. Datums of Composite Section derived from Tibui are excluded. First appearance datums= FAD, last appearance datums=LAD.

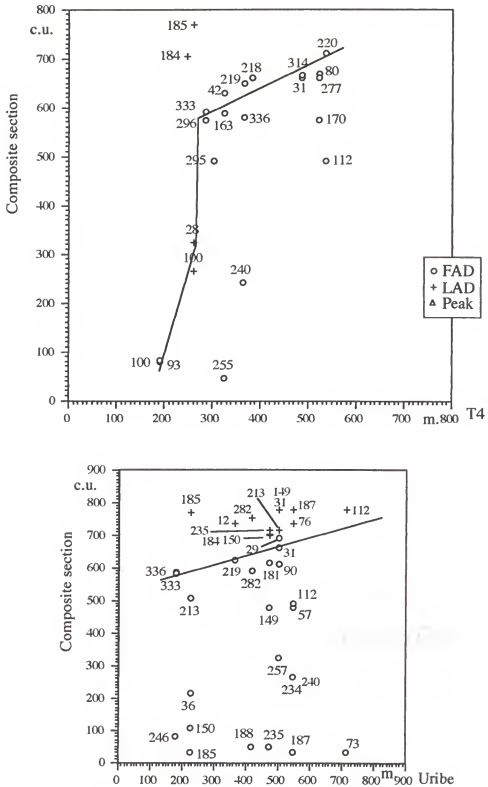


Figure 5-9. Second round of correlation. Composite Section versus T4 and Uribe. See Table 5-6 for the names of the taxa used in graphic correlation. c.u.=composite units. Datums of Composite Section derived from T4 and Uribe are excluded.

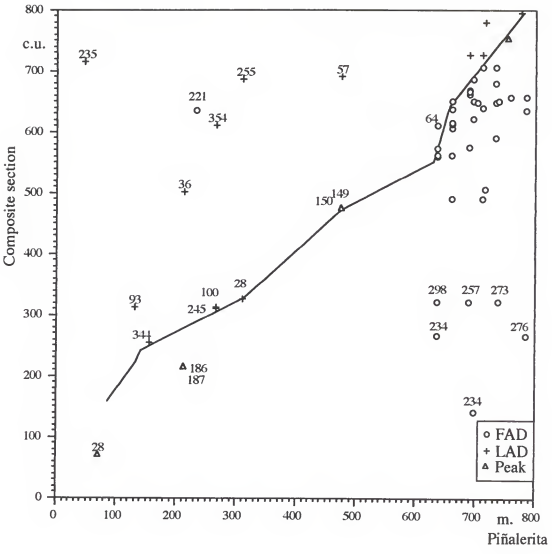


Figure 5-10. Second round of correlation. Composite Section versus Piñalerita. See Table 5-6 for the names of the taxa used in graphic correlation. c.u.=composite units. Datums of Composite Section derived from Piñalerita are excluded. First appearance datums= FAD, last appearance datums=LAD.

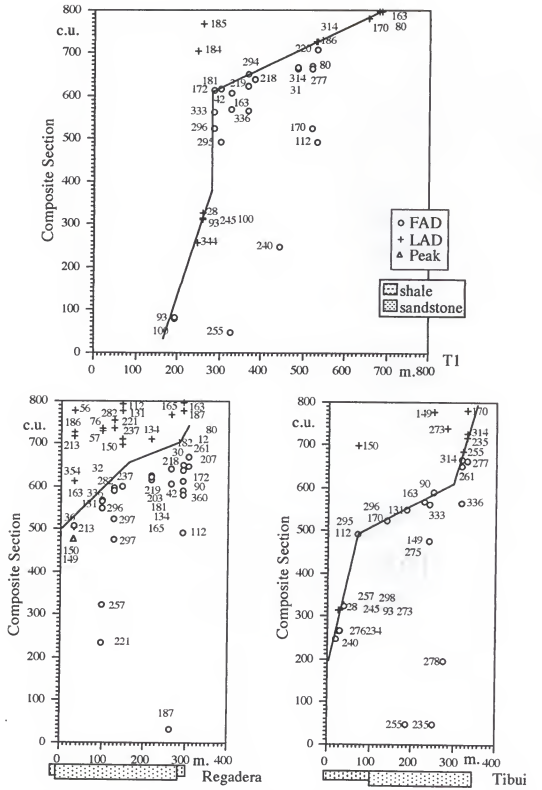


Figure 5-11. Line of correlation for well T1, Regadera, and Tibui sections versus Composite Section. See Table 5-6 for names of the taxa used in graphic correlation. First appearance datums= FAD, last appearance datums=LAD.

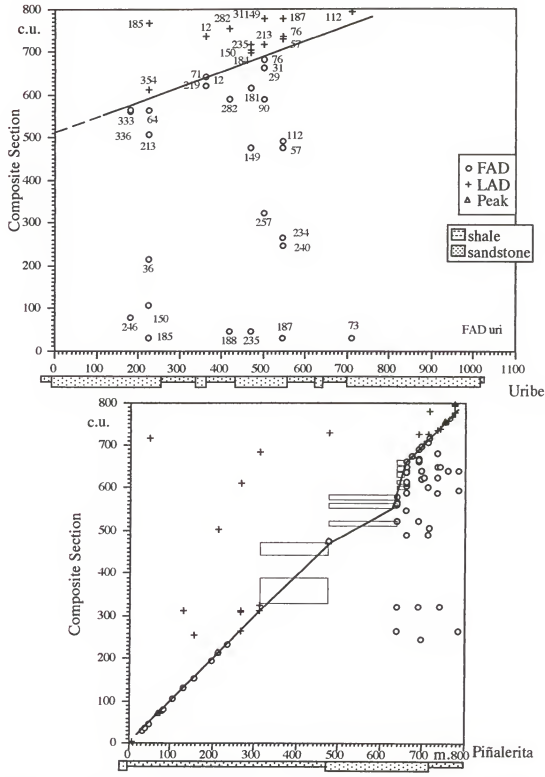


Figure 5-12. Line of correlation for Uribe and Piñalerita sections versus Composite Section. See Table 5-6 for names of the taxa used in graphic correlation. Boxes indicate strata down to next lower sample for first appearance datums (FAD) and up to next higher sample for last appearance datums (LAD) to take large gaps in sample interval into account.

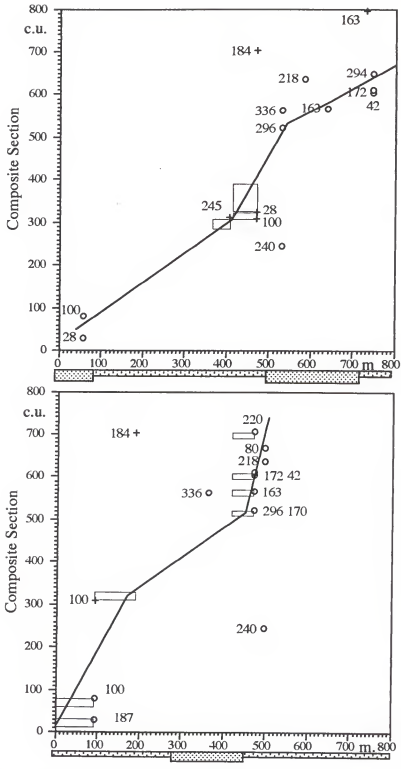


Figure 5-13. Line of correlation for Rubio Road and Paz de Río sections versus Composite Section. Sections after Germeraad *et al.* (1968). See Table 5-6 for names of the taxa used in graphic correlation. Boxes indicate strata down to next lower sample for first appearance datums (FAD) and up to next higher sample for last appearance datums (LAD) to take large gaps in sample interval into account

Table 5-3. Palynomorph distribution in samples from the Piñalerita section

Taxa	Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Aglaeoreidia? "foveolatus"							6																														
Araucariaciates "rugulatus"																1																					
Araucariaciates "scabratus"						1				1													1														
Baculamonocolpites "bimodalis"																									1												
Baculamonocolpites "curubensis"																									1			3		1							
Baculatisporites "irregularis"																												1							1		
Baculatisporites "soleus"																												1									
Bacutriporites "echinatus"																												1									
Bombacacidites "caldensis"								1																													
Bombacacidites "etayoi"										1		1				1																					
Bombacacidites "fossureticulatus"																								3	8	3	2	1		1							
Bombacacidites "gentryi"																																					1
Bombacacidites "missoides"																																1					
Bombacacidites "protociriloensis"																												1								1	
Bombacacidites "protofoveoreticulatus'	1			2		1			2		2	1																									
Bombacacidites "sabanensis"																														1	6					7	
Bombacacidites "simplireticulensis"																								1													
Bombacacidites annae		34	70		4	18	5	9	3		29		3	60		6	3																				
Bombacacidites brevis																								1		1		1		2	1	9	7	7	4	19
Bombacacidites foveoreticulatus																																					1
Bombacacidites nacimientoensis																						1		1		1		3	1	1	1			2		
Bombacacidites soleaformis																																					1
Bombacacidites sp. C		1																																			
Brevitricolpites "macroexinatus"																																	1			1	
Brevitricolpites "microechinatus"														1																							
Brevitricolpites "scabratus"																1																					
Chomotriletes minor																							2		1												
Cicatricosisporites "infrafoveolatus"	1																																				
Cicatricosisporites dorogensis																						10		1	4	7	6	5	15	4	22	26	64	15	89	14
C. dorogensis subsp. minor forv. rugulatearis																						2		1									1			1
Cicatricososporites "decussatus"																															1					
Cicatricososporites eocenicus																								1						3	3	2		1		1
Clavamonocolpites "macroclavatus"																																		4	1	3
Clavatisporites mutisi										1																										
Clavatricolpites "densoclavatus"																						3		2	15	9	8	13	2	6	4		4	2	1	4
Colombipollis tropicalis										1																										

Table 5-3--continued.

Taxa Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Cricotriporites "macropori"																			1												1		1		4	
Cricotriporites guianensis																		1																		
Cricotriporites minutipori																												1								
Cricrotriporites "porielongatus"																															1	1		2	1	
Crototricolpites "protoannemariae"			1	6				3	1		2		4		31																					
Ctenolophonidites "cruciatus"																								1												
Curvimonocolpites inornatus		5	2	2	1	4		2																												
Cyclusphaera "scabratus"																			6		1			1		1				1	6	1	6	2	2	15
Echimonocolpites "tenuiechinatus"					1				4	1					3																					
Echinatisporis "brevispinosus"																					1										4	5		1	4	
Echinatisporis "microechinatus"																						1	1	1												
Echinatisporis "obscurus"			1								3				1	1																	1		1	
Echinatisporis "portae"																								1												
Echinatisporis? "cingulatus"																														2						
Echipericolpites "brevicolpatus"													1																							
Echiperiporites "scabratus"				1																																
Echiperiporites estelae																								2				1	1	2		3	5	10		
Echitetracolpites "echinatus"																								1	1			6		1	1	1		1	1	3
Echitetracolpites "tenuiexinatus"																												5		4	1	1	1		2	5
Echitricolpites "linearis"											2		2																							
Echitriporites "annulatus"																															1					
Echitriporites "spissuexinatus"			1																																	
Echitriporites "variabilis"																					1			3	1	1	3	1	1	1	4			3		16
Echitriporites trianguliformis var. "orbicularis"																					6			2	4	8	3	7	2	12	4	4	2	3		1
Ephedripites vanegensis						1	1	4	2																											
Fossutricolporites "microreticulatus"																		1																		
Foveodiporites guianensis	2																																			
Foveotricolpites "costatus"																					1															
Foveotricolpites perforatus							1	1		2			4		2																					
Foveotricolporites "brevicolpatus"																					1															
Foveotricolporites "fossulatus"																								2				1		3						
Foveotricolporites "marginatus"																														1						
Foveotricolporites "poricostatus"																2																				
Foveotricolporites "rugulatus"																					1												1	2	3	11
Foveotriletes "fossulatus"																														1						1
Foveotriporites "poricostatus"																																				2
Foveotriporites hammenii																					12			2				2	2	3	2		1	3		

Table 5-3--continued.

Taxa Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Gemmamonocolpites "mammiformis"			1																											2						
Gemmamonocolpites "megagemmatus"																																				
Gemmamonocolpites "perfectus"																								1		1				1						
Gemmamonocolpites gemmatus		5				1																														
Ischyosporites "problematicus"											4	1					1																			
Jandufouria "minor"																							1							1	4	8		2	1	6
Jussitriporites "psilatus"		3	1	1	1	1		2		1	2	1	8																							
Jussitriporites undulatus																					1									2		1		1		
Kirchheimerisporites "tenuiradiatus"																															3					
Ladakhipollenites rubini																											1	1			2					
Ladakhipollenites simplex																									2	1										
Laevigatasporites "laevigatus"				1					2		5		9		1																					
Laevigatosporites "barcoi"							1																													
Laevigatosporites "tenuiexinatus"																								1												
Laevigatosporites tibui				1		2		1	2		25	6	9		13	3			8		22	1	4	4	48	126	169	186	39	65	39	72	52	27	41	57
Longapertites "ornatus"																										1		2		1						1
Longapertites microfoveolatus									4	2																										
Longapertites proxapertitoides var. *reticuloides*																	246	1									1	5	2	2	3	1		1		
Longapertites proxapertitoides var. *proxapertitoides*								1					1	1	1		148	1							1											
Luminidites "colombianensis"																								1								1				
M. franciscoi var. *franciscoi*	1	11	8	6	3	43	17	35	2	15	7		14		17	1	1	1	1		9	1	3	1	32	10	22	22	6	5	15	4	5	6	7	7
Mauritiidites franciscoi var. *minutus*			1		1			1	3	2	1		4		2	1			5		1				5	7	13	10	1	2	1			3	2	1
Mauritiidites franciscoi var. *pachyexinatus*																						2				3	3	1	1							
Microfoveolatosporis skottsbergii																																				1
Momipites "pachyexinatus"																									1			4		1				2	2
Momipites africanus			2	2																																
Monoporopollenites annulatus																			6		1			1	1	1			1	2	3	3	1	3	3	
Nothofagidites "huertasi"																																	5	13		
Osmundacidites "dispergatus"			2																																	
Osmundacidites "minor"																																4	2			
Perfotricolpites digitatus																								1				1								
Periretisyncolpites "inciertus"			3		2								1																							
Perisyncolporites pokornyi																					6			4	3	1	1	4	3	10	13	9	14	11	49	7
Polypodiaceoisporites? "fossulatus"							1		2										1					1				1		2	2	6			3	
Polypodiisporites "densus"																																				1
Polypodiisporites "echinatus"									1																											
Polypodiisporites "pachyexinatus"																3																				

Table 5-3--continued.

Taxa Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Polypodiisporites "protousmensis"				1				1		1	1				1	1					1			2	33	32	35	13	22	31	21	86	12	12	15	14
Polypodiisporites specious																					1															
Propylipollis "pseudocostatus"																					1															
Proxapertites cursus		1	2	1	1	97	1	253		8	6	4	6				2								1	1									
Proxapertites humbertoides			13	1					1	1	2		10						2	1	1										2			1		
Proxapertites magnus		2		16	6	12	16	5	6	6	18	6	57		4	2	1							1			1								
Proxapertites operculatus			1	1	1	61	4	61	1	21	4	4	26	2	25	4	1				1					1			2					1	
Proxapertites psilatus					1				1										2	3	1			2			1	4	1	2					3
Psilabrevitricolpites "costatus"			1								9																								
Psilabrevitricolporites "costatus"																												1							
Psilabrevitricolporites "operculatus"																											1								
Psilabrevitricolporites simpliformis				1	2								1		1																				
Psilamonocolpites grandis		57	4	3	2		6	1				1	2			1																			
Psilamonocolpites medius		8	4	15	5	4	2	8	3	1	2		6		3	2	1		4		3		5	1	6		1			5	4	8	6	3	4	3
Psilaperiporites "enigmaticus"	1																																			
Psilaperiporites "pachyexinatus"																																		1		
Psilaperiporites "pauciporatus"																					6			3	10	9	1	6	2	1		1		2		
Psilastephanocolpites "marginatus"																												1								1
Psilastephanocolpites "punctum"																																				
Psilastephanocolporites "brevicolpatus"																					1			1				1		1						
Psilastephanocolporites "pachyexinatus"																								2		2					1					
Psilastephanocolporites "psilatus"																														1			1	4	2	4
Psilastephanocolporites fissilis																						1		1						2				2	1	
Psilastephanoporites "distinctus"																														1	1	1	1			
Psilastephanoporites "*scabratus*"															1																					
Psilasyncolporites "psilatus"																													1							
Psilatricolporites "crassicolumellatus"																														1						
Psilatricolporites "orbicularis"																												1								
Psilatricolporites "poricostatus"																												1								
Psilatricolporites "singularis"																												1								
Psilatricolporites "spongiosus"				4					2		3				14	1																				
Psilatricolporites crassus																					31	3		11	36	34	2	13	7	63	4	1	3	1	6	17
Psilatricolporites maculosus																									2			2	3	4	2	5	3	3	5	4
Psilatricolporites operculatus																											1									
Psilatricolporites transversalis														1					2			2		4	1	1	4	1		1						
Psilatricolporites triangularis																									1					1						1
Racemonocolpites "costagemmatus"																			1																	

Table 5-3--continued.

Taxa Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Racemonocolpites facilis																			1		1												1			1
Racemonocolpites racematus					1																															
Retibrevitricolpites "costatus"																																				2
Retibrevitricolpites "santanderensis"																											1									
Retibrevitricolpites retibolus																											6									
Retibrevitricolpites triangulatus																									1	1	3									
Retibrevitricolporites "grandis"																			9	1	2	1		2	5			1		2	3	1	4	30	12	38
Retibrevitricolporites "speciosus"																			1								10	2		3					
Retidiporites "poricostatus"						1																														
Retidiporites elongatus											1																									
Retidiporites magdalenensis	33				2	38	2	5							2																					
Retimonocolpites "ovatum"						20		9		3	180		33		25	14		1	1		4	1		4	9	8	3	6	2	7	7	5	5	2	8	12
Retimonocolpites regio	3	9	18	16	5	5	6	10	3	3				1				1																		
Retipollenites "baculatus"		1																																		
Retipollenites "magnus"			1													1																				
Retistephanocolpites "fossulatus"																											1		1		1	6	6	1	8	2	9
Retistephanocolpites "gradatum"																													1							
Retistephanocolpites "inciertus"																															1					
Retistephanocolpites angeli					2				1		2		2		1	2																				
Retistephanocolporites "fossulatus"																								3							1					
Retistephanocolporites festivus																								1		2		1		1		4	3	2		3
Retistephanoporites "crassiexinatus"																								1												
Retistephanoporites "minutipori"																								1	1	2	3	11	3	16	5					
Retistephanoporites angelicus																															1	19	12	7	12	4
Retisyncolporites "complicatus"																																				1
Retisyncolporites "delicatus"																			1		1															
Retitricolpites "baculensis"									1												1							2	2	1					2	5
Retitricolpites "costatus"																																		1		
Retitricolpites "marginocostatus"																						1														
Retitricolpites "peculiaris"							4				1		2		7																					
Retitricolpites "protoclarensis"	2	1	3	3					2	1	3		2		2																					
Retitricolpites absolutus																															1					
Retitricolpites antonii																									2											
Retitricolpites clarensis																		3			1	1			1		1			1						1
Retitricolpites florentinus																																				1
Retitricolpites magnus																					1			6	28	15	4	9	4	4	1		1			
Retitricolpites saturum											1				1																					

Table 5-3--continued.

Taxa	Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Retitricolporites	"arctus"																												3								
Retitricolporites	"delicatus"																														1	1	1				
Retitricolporites	"distinctus"											1		2																							
Retitricolporites	"insolitus"																														1						1
Retitricolporites	"longicolpis"																															2					
Retitricolporites	"marginatus"																								1	1											
Retitricolporites	"minutus"																										1	2				2	1	1	2		1
Retitricolporites	"pachynexinatus"																												1						1		2
Retitricolporites	"poricostatus"																			1										1							
Retitricolporites	"tropicalis"									10	2					2																					
Retitricolporites	"vestibulatus"																2		1				1					1				1			1		2
Retitricolporites cienagensis																											1						2				
Retitricolporites guianensis																						3			3	19	17	9	4	17	12	10		1	5	8	1
Retitricolporites hispidus																												5	1	1	1	1					6
Retitricolporites irregularis																				1		1			1		3		1		1	2		1		2	3
Retitricolporites mariposus																			1																		
Retitricolporites medius																				4	1					3											4
Retitricolporites squarrosus																											1										
Retitriletes	"enigmaticus"																																	2		2	
Retitriporites	"amplireticulatus"											2																									
Retitriporites	"annulatus"					1																															
Retitriporites	"pachyexinatus"																												1								
Retitriporites	"peculiaris"																											1									
Retitriporites	"perforatus"																														1						
Retitriporites	"poricostatus"																								1										1		
Rugotricolporites felix																									1												
Scabrastephanocolpites	"casanaris"																		1																		
Scabratricolporites	"tomassoi"																												1	1	1		1				
Spinizonocolpites	"breviechinatus"	1	2		1					1	1	2				4																					
Spinizonocolpites	"grandis"																					20	3		5	7	9	2	6	6	4						
Spinizonocolpites	"pachyexinatus"																5																				
Spirosyncolpites spiralis																				15		3	4	2	1	3	1	1	1			9		5	8	5	25
Striatricolpites	"orinocus"									1			1							2		2			1				1		1	6	3	3	2	3	9
Striatricolpites catatumbus															1																					
Striatricolpites minor																																					
Striatricolporites	"digitatus"				1																																

Table 5-3--continued.

Taxa Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Striatricolporites "reticulatus"															1	1			1		1										1					
Syncolporites "verrucatus"																1																				
Syncolporites lisamae										1																										
Tuberositriletes "verrucatus"																					1										2	3		2	2	3
Tuberositriletes? "inciertus"									2										1																	
Ulmoideipites krempii		1													1																					
Verrustephanocolpites "rugulatus"																		1							1											
Verrustephanoporites "gemmatus"																														1	1					
Verrutricolpites "irregularis"																																				1
Verrutricolporites *"reticulatus"*																			1	1	1			2	2	3				7	36		1			4
Zlivisporis blanensis													11			1																				
Zonocostites "minor"																														7	1	2	1			
"Psilatriletes" sp. A		2	12	10	12	3	7	29	10	22	24	2	5		36	16	2	3	13		17	1		1	31	46	35	25	43	65	17	26	24	27	38	24
"Psilatriletes" sp. B			3	2		16	5	59	4	5	37	5	29		33	22	2		15		8	1	2	1	3	3	2	2	1	3	5	4	2	3	7	1
"Psilatriletes" sp. C																					17			1	21	9	10	3	3	3	1	1		2		1
Acritarcha sp. A																					1															
Acritarcha sp. B																					1															
Acritarcha sp. C																										1										
Bacuinaperturites sp. A																					1															
Bombacacidites sp. A			1																																	
Bombacacidites sp. B					1																															
Cicatricosisporites sp. A		1																																		
Cingulatisporites sp. A			1																																	
Echidiporites sp. A	1																																			
Echimonocolpites sp. A																														1						
Echimonocolpites sp. C													1																							
Echinosporis sp. A																											1									
Echitricolpites sp. A																																	1			
Echitriporites sp. B															1																					
Ephedripites sp. A																													1							
Fossulatisporites sp. A								1																												
Fossulatisporites sp. B																														1						
Fossustephanocolpites sp. A																								3												
Foveotricolpites sp. A																			1																	
Foveotriletes sp. A															1																					
Foveotriletes sp. B																																	1			
Gemmainaperturites? sp. A		1																																		

Table 5-3--continued.

Taxa	Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Incertae sedis	sp. A																															1					
Ladakhipollenites	sp. A																								1												
Ladakhipollenites	sp. B																												2								
Laevigatasporites	sp. A		14	1																																	
Laevigatasporites	sp. B					1											1																				
Longapertites?	sp. A		17																																		
Mauritiidites	sp. A											2																									
Microfoveolatosporis	sp. A													4		2																					
Nematosphaeropsis	sp. A																				3																
Polypodiisporites	sp. A								1																												
Psilasyncolporites	sp. A																						1														
Psilatriporites	sp. A																								1											1	
Psilatriporites	sp. B																																			1	1
Psilodiporites	sp. A								2																												
Retibrevitricolpites	sp. A																																			1	
Retimonocolpites	sp. A																												1								
Retimonocolpites	sp. B						1																														
Retistephanoporites	sp. A																																			1	
Retisyncolporites	sp. A																															3					
Retitricolpites	sp. A																			1																	
Retitricolpites	sp. B																						1												1		
Retitricolporites	sp. A					1				2						6																					
Retitricolporites	sp. B				1																																
Retitricolporites	sp. C																															1					
Retitricolporites	sp. D																			1																	
Retitricolporites	sp. E																						1														
Retitricolporites	sp. F																												1								
Retitriporites	sp. A																														1						1
Rugotricolporites	sp. A																						1														
Rugotricolporites	sp. B																								1												
Rugulatisporites	sp. A																																1				
Scabrastephanoporites	sp. A		1																																		
Scabratisporites	sp. A																																		1		
Scabratricolpites	sp. A																											1									
Scabratriporites	sp. A																																				1
Striatricolporites	sp. A					1																															
Striatriporites	sp. A																							1													

Table 5-3--continued.

Taxa Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Syncolpites sp. A		3																																		
Syncolporites sp. B																																		1		
Tuberositriletes sp. B					1																															
Verrustephanoporites sp. A	1																																			
Verruticolporites sp. A																												1								
Verruticolporites sp. B																				1																
Verruticolporites sp. C																															2					
Achomosphaera sp. A																					6			1		1		1	2	1						
Cordosphaeridium sp. A																					30							1	1	4						
Coronifera sp. A																1																				
Dinocyst indet.			1													1					22					2		2								
Glaphyrocysta sp. A																										2										
Homotryblium floripes																								1	3	3	1	10	44	3						
Hystrichosphaeridium sp. A																								1						1						
Incertae dinocyst C																														1						
Lingulodinium cf. *sicula*																										1		1		1						
Microforaminiferal lining		3		4	1																5	1													
Pediastrum		1	21	1	1															2																
Polysphaeridium sp. A																					52		1		1	2		2	4	2	5					
Pterospermella sp.							1																													
Spiniferites sp. A																					7															
Systematophora? sp. A																								1												
Trachelomona sp.																																				
Aequitriradites verrucosus (RW)					1																															
Bombacacidites annae (RW)																																				1
Buttinia andreevi (RW)																			1																	
Circulodinium distinctum (RW?)																		1																		
Foveotriletes margaritae (RW?)																									1							1				
Oligosphaeridium sp. (RW)			2															1																		
Bacutricolpites sp.																			1																	
Bombacacidites sp.		1			4			3	1		2	1	3		2								1					2					1		
Brevitricolporites sp.																						1														
Cingulatisporites sp.																	1																			
Clavastephanocolpites sp.																																			2	
Clavatricolpites sp.													1																							
Clavatriporites sp.						1																														
Echipollenites sp.																			1														1	1	3	

Table 5-3--continued.

Taxa Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Echistephanoporites sp.																																			1	
Echitriporites sp.															1						1				1		1	2								
Foveomonocolpites sp.																1																				
Foveostephanocolpites sp.																									1											
Foveostephanocolporites sp.																						1														
Foveotricolpites sp.																								1												
Foveotricolporites sp.																						1														
Foveotriletes sp.																1					2								1							
Foveotriporites sp.																										1										
Incertae sedis sp.																												1			1				1	
Jussitriporites sp.															1	1																				
Ladakhipollenites sp.										2	1				2												1									
Laevigatasporites sp.										1											1	1	1													
Laevigatosporites sp.				5						1									1																	
Leiosphaeridia sp.																			1																	
Megaspore																		5																		
Pollen indet.																											1				1					
Psilabrevitricolpites sp.																											1									
Psilamonocolpites sp.		1		6			5		58			2	1		1	2									2	3	1	5	1	1	2					
Psilastephanoporites sp.																						1														
Psilatricolporites sp.										2											2	2	2		2			3	1		1		1	2	1	1
Psilatriporites sp.											2		1									1													1	6
Retibrevitricolporites sp.																											1									
Retimonocolpites sp.						1	1	1	22	1	1	1	2		1				1						1										1	
Retimonoletes sp.																										1										
Retipollenites sp.			10																														1			
Retistephanoporites sp.																					1		1													
Retisyncolporites sp.										1															1											
Retitricolpites sp.							1		2	1	4		2		2	1			7	1	3	2		4	3	6				7	5		1	3	2	5
Retitricolporites sp.			1		3		1		2		3								9		5	1		1	11	3	3	1	3	3	4	5	7	3	3	3
Retitriletes sp.										1									1																	
Retitriporites sp.											1										1		2		1							1	1			
Rugopollenites sp.																			1																	
Rugutriletes sp.											1																									
Scabrastephanoporites sp.																																			1	
Scabratricolpites sp.																			1																	
Scabratricolporites sp.			1																			1				5									

Table 5-3--continued.

Taxa \ Sample code	1	4	5	6	7	8	9	10	11	12	15	16	17	18	19	21	25	27	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49
Scabratriporites sp.													1									1		1												4	
Spinizonocolpites sp.		1											1								1			2												
Striatricolporites sp.																			2										1							4
Verrucatosporites sp.												1							1		10			1											
Verrustephanoporites sp.																									1											
Verrutriletes sp.									1	1					1							1										1				
Zonotriletes sp.										4			1																							

Key to sample code (meters from base of Arcillas de El Limbo Formation). Samples that are not in the range chart were sterile for palynomorphs

1 = NA -2 (-5.4 m.)
2 = NA -1 (-3.6 m.)
3 = N 0+60 (-1.2 m.)
4 = N 4 (5.4 m.)
5 = N 18 (30.6 m.)
6 = N 21 +100 (37 m.)
7 = N 27 (46.8 m.)
8 = N 45 (79.2 m.)
9 = NA 46 (81 m.)
10 = NA 59+90 (105.3 m.)
11 = N 74 (131.4 m.)
12 = N 87 (154.8 m.)
13 = N 90 (160.2 m.)
14 = N 100 (178.2 m.)
15 = N 110 (196.2 m.)
16 = N 114 (203.4 m.)
17 = N 120 (214.2 m.)
18 = N 131 (234 m.)
19 = N 149 (266.4 m.)
20 = N 157 (280.8 m.)
21 = N 174 (311.4 m.)
22 = N 181 (324 m.)
23 = N 201 (360 m.)
24 = N 216 (387 m.)
25 = N 241 (432 m.)
26 = N 254 (455.4 m.)
27 = N 265 (475.2 m.)
28 = N 265+150 (476.7 m.)
29 = N 283 (507.6 m.)
30 = N 325 (583.2 m.)
31 = N 349 (626.4 m.)
32 = N 354+120 (636.6 m.)
33 = PIN 0 (639 m.)
34 = PIN 12 (660.6 m.)
35 = PIN 19+60 (673.8 m.)
36 = PIN 24+90 (682.2 m.)
37 = PIN 28+0 (689.4 m.)
38 = PIN 32+0 (696.6 m.)
39 = PIN 35+90 (702.9 m.)
40 = PIN 39+166 (710.8 m.)
41 = PIN 42+100 (715.6 m.)
42 = PIN 47+100 (724.9 m.)
43 = PIN 52+110 (733.7 m.)
44 = PIN 55+30 (738.3 m.)
45 = PIN 63+20 (752.6 m.)
46 = PIN 66+80 (758.6 m.)
47 = PIN 71+10 (766.8 m.)
48 = PIN 75+160 (775.6 m.)
49 = PIN 81+0 (784.8 m.)

Table 5-4. Palynomorph distribution in samples from the Regadera section

Taxa sample code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Araucariaciates "rugulatus"							1										
Baculamonocolpites "curubensis"																	1
Bombacacidites "dilcheroi"				1													
Bombacacidites "psilatus"				1													
Bombacacidites foveoreticulatus															1		
Bombacacidites soleaformis								1									
Brevitricolpites "microechinatus"				2													
Cicatricosispories dorogensis															2	33	90
C. dorogensis subsp. minor forv. rugulatearis																	1
Clavatricolpites "densoclavatus"				7			2	2								3	1
Cricotriporites "macropori"				1													
Cricotriporites guianensis				2			3										
Cyclusphaera "scabratus"				1			2	2								1	2
Echinatisporis "brevispinosus"				1				1									
Echinatisporis? "cingulatus"				3			1										
Echiperiporites estelae																	1
Echitetracolpites "echinatus"																3	3
Echitetracolpites "tenuiexinatus"																7	4
Echitriporites "retiechinatus"							2										
Echitriporites trianguliformis var. "orbicularis"																13	
Foveotricolporites "rugulatus"																3	1
Foveotriporites hammenii							2	2	4								
Jussitriporites undulatus							1	1	2								
Ladakhipollenites "gemmatus"				1													
Ladakhipollenites simplex													1				
Laevigatasporites "laevigatus"							1										
Laevigatosporites tibui				3			1	7	131							19	25
L. proxapertitoides var. *reticuloides*				25													1
L. proxapertitoides var. *proxapertitoides*				145			1		1								
Margocolporites vanwijhei				7													
Mauritiidites franciscoi var. *franciscoi*				4			2	3	5						2	10	14
Mauritiidites franciscoi var. *minutus*							1	2	2								
Mauritiidites franciscoi var. *pachyexinatus*				1													
Microfoveolatosporis skottsbergii				1													
Monoporopollenites annulatus							2	2	1							1	
Nothofagidites "huertasi"															1		
Nothofagidites "lolongatus"																3	
Perisyncolporites pokornyi																6	7
Polypodiisporites "breviverrucatus"								1								1	
Polypodiisporites "echinatus"				11				1									
Polypodiisporites specious													4		7	7	16
Proxapertites magnus				1													
Proxapertites operculatus															3	1	
Psilamonocolpites medius				14				1	1							3	1
Psilastephanocolporites "psilatus"													1				

Table 5-4--continued.

Taxa sample code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Psilastephanoporites "distinctus"																1	
Psilasyncolporites "fastigiatus"				2				1									
Psilatricolporites "orbicularis"									1								
Psilatricolporites crassus																2	85
Psilatricolporites maculosus													1			5	12
Psilatricolporites transversalis							1	1									
Retibrevitricolpites "santanderensis"									3								
Retibrevitricolporites "grandis"				10			1	2									
Retimonocolpites "ovatum"				7			2	2	3				7		1		
Retistephanocolpites "fossulatus"									1								1
Retistephanocolporites festivus							1	6									
Retistephanoporites angelicus																6	15
Retisyncolporites angularis																1	1
Retitricolpites "perforatus"				1													
Retitricolporites "delicatus"								1									
Retitricolporites "vestibulatus"									1								
Retitricolporites irregularis								1								2	
Retitricolporites mariposus								1									
Scabratriporites "bellus"																	1
Spirosyncolpites spiralis				11			3	7								1	
Striatricolpites "tenuistriatus"				2					1								
Striatricolpites catatumbus							3	1					1				
Syncolporites marginatus							1										
Ulmoideipites krempii				12													
Verrutricolporites "reticulatus"																1	
Wilsonipites margocolpatus								1									
"Psilatriletes" sp. A				45			2		2						3	13	53
"Psilatriletes" sp. B				17			2	2	2						10		5
"Psilatriletes" sp. C				49					3						2		10
Camarozonosporites sp. A								1									
Cingulatisporites sp. B								1									
Foveotriletes sp. B																1	
Incertae sedis sp. B															1		
Laevigatosporites sp. A																1	
Mauritiidites sp. A				1													1
Psilastephanoporites sp. A									1								
Scabratisporites sp. A													1				
Tuberositriletes sp. A																1	
Algae				1													
Dinocyst indet.				1													
Incertae dinocyst A				1													
Pediastrum				3			2	8									
Polysphaeridium sp. A																1	4
Circulodinium distinctum (RW?)				5													
Oligosphaeridium sp. (RW)				1													
Proxapertites magnus (RW)																	1

Table 5-4--continued.

Taxa sample code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Senegalinium sp. A (RW?)				6													
Spiniferites sp. (RW?)				1													
Bombacacidites sp.				2			1										
Cingulatisporites sp.									1								
Clavatricolpites sp.																1	
Clavatricolporites sp.									3								
Colombipollis sp.				1													
Echistephanoporites sp.																	4
Echitriporites sp.								1									
Ladakhipollenites sp.																1	
Laevigatosporites sp.													1				
Pollen indet.																	1
Psilatriporites sp.				1													
Retistephanoporites sp.																11	1
Retitricolpites sp.				17			2	1	2							3	
Retitricolporites sp.				6			7						1			1	
Rugotriporites sp.																1	
Scabrastephanoporites sp.															1		
Spinizonocolpites sp.																	2
Striatricolpites sp.							1										
Verrutriletes sp.																	1

Key to sample code (meters from base of Mirador Formation)

1 = RE 39 (-12m.)
2 = RE 46 (-1.5m.)
3 = RE 49+130 (4.3m.)
4 = RE 67+120 (31.2m.)
5 = RE 83 (54m.)
6 = RE 98 (76.5m.)
7 = RE 113 (99m.)
8 = RE 132 (127.5m.)
9 = RE 143+120 (145.2m.)
10 = RE 153 (159m.)
11 = RE 170+40 (184.9m.)
12 = RE 186 (208.5m.)
13 = RE 190+10 (214.6m.)
14 = RE 220 (259.5m.)
15 = RE 222+100 (263.5m.)
16 = RE 241+40 (291.4m.)
17 = RE 251+30 (306.3m.)

Table 5-5. Palynomorph distribution in samples from the Uribe section

Taxa	sample code 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Anacolosidites ariani										1						1				2			
Baculamonocolpites "angustus"																1							
Baculamonocolpites "curubensis"													1										
Baculatisporites "soleus"								1							1								
Bacumorphomonocolpites tausae								1															
Bombacacidites "psilatus"																15	1			1			
Bombacacidites "simplireticulensis"																					1		
Bombacacidites brevis																	2						
Bombacacidites nacimientoensis																	1						
Brevitricolpites "microechinatus"									4				1							2	18		
Camarozonosporites "inciertus"																		1			2		
Chomotriletes minor												2		1	8	5							
Cricotriporites guianensis																		3					
Crototricolpites cf. *annemariae*									1														
Cyclusphaera "scabratus"									1								2	1		3	4		
Echinatisporis "brevispinosus"													2										
Echinatisporis "obscurus"																				1	1		
Echinatisporis? "cingulatus"																	1	1					
Echitriporites "variabilis"																2							
Echitriporites trianguliformis var. "orbicularis"																	6						
Foveotriporites hammenii																		2		2			
Gemmamonocolpites "ambigemmatus"																		2					
Laevigatosporites tibui							2		1						1	2		51		13	14		
Longapertites proxapertitoides var. *reticuloides*																5	1						
Longapertites proxapertitoides var. *proxapertitoides*									1							1							
Mauritiidites franciscoi var. *franciscoi*												1		1	4	1	7						
Mauritiidites franciscoi var. *minutus*									7								1	1					
Mauritiidites franciscoi var. *pachyexinatus*																		1					
Polypodiaceoisporites? "fossulatus"																		3		11	16		
Polypodilsporites "brevis"									2							1							
Polypodiisporites "breviverrucatus"																		1		1	1		
Polypodiisporites "densus"																				1			
Polypodiisporites "echinatus"									11														
Polypodiisporites specious																2		5					
Proxapertites cursus																1							
Proxapertites humbertoides									2														
Proxapertites operculatus																		5					
Proxapertites psilatus															2								
Proxapertites verrucatus							1	1	1														
Psilamonocolpites medius															1	3	1						
Psilastephanoporites "annulatus"																1							
Psilatricolporites "orbicularis"									3								1						
Psilatricolporites maculosus													1							2			
Psilatriporites "tenuiexinatus"									1						1								

Table 5-5--continued.

Taxa sample code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Pteridacidites "cucutensis"																				1	1		
Racemonocolpites "costagemmatus"										1													
Racemonocolpites facilis																		1		1	1		
Racemonocolpites racematus																1							
Retibrevitricolpites triangulatus																		2					
Retibrevitricolporites "grandis"										1								2					
Retibrevitricolporites "speciosus"																		1					
Retimonocolpites "ovatum"								1		9		2				17	1	7		1			
Retistephanocolporites festivus																	2						
Retistephanoporites "regaloi"																				1			
Retitricolporites "delicatus"															1								
Retitricolporites "grandis"																		1					
Retitriporites "poricostatus"																				1			
Scabratricolporites "amplocolpatus"										1								2					
Spinizonocolpites "brevibaculatus"								1		10						3				1			
Spinizonocolpites "pachyexinatus"										1							1						
Spinizonocolpites "pluribaculatus"																1							
Spirosyncolpites spiralis								1		1		1			3	1	3	3		10			
Striatricolpites "tenuistriatus"												1			1			8					
Striatricolpites catatumbus								3							1	1		1			1		
Tuberositriletes "verrucatus"																				1			
Ulmoideipites krempii										6													
Verrumonocolpites "romatus"																1							
"Psilatriletes" sp. A				5				1		11		1	1	1	21		4	4		24	47		
"Psilatriletes" sp. B								4	6	11		5	1	5	25		6	3		20	13		
"Psilatriletes" sp. C																	1	2		9	1		
Acritarcha sp. A																	1						
Clavamonocolpites? sp. A																		1					
Echimonocolpites sp. B																				1			
Echinatisporis sp. A										1													
Echitriporites? sp. A										1													
Foveotricolporites sp. A																		1					
Gemmainaperturites? sp. A																				1			
Incertae sedis sp. C										1													
Laevigatasporites sp. C												1											
Laevigatasporites sp. D																3							
Longapertites sp. B																		2					
Psilastephanocolporites sp. A																				1			
Psilatriporites sp. C																		1					
Retibrevitricolpites sp. A																		1					
Retistephanoporites sp. B								1															
Retitricolporites sp. A								1															
Striatricolporites sp. A																11							
Syncolporites sp. A								1															
Tuberositriletes sp. A														1									
Algae								1															
Algae A			3																				

Table 5-5--continued.

Taxa sample code	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Dinocyst indet.										2			1		1	2	1						
Incertae dinocyst B										1													
Incertae dinocyst C										1													
Pediastrum										2			1										
Spiniferites cf. *mirabilis*															1								
Alisogymnium euclaense (RW)																	1						
Buttinia andreevi (RW)								2															
Dinogymnium acuminatum (RW)																				1	1		
Dinogymnium sp. (RW)				1						1						3					1		
Dinogymnium undulosum (RW)																5							
Odontochitina sp. (RW)				2									1		1								
Oligosphaeridium sp. (RW)																1							
Palaeohystrichophora infusorioides (RW)										2													
Periretisyncolpites giganteus (RW)																				1			
Proxapertites magnus (RW)																1					7		
Senegalinium sp. A (RW?)										1						9							
Spinidinium sp. (RW?)													1			1							
Spinozonocolpites baculatus (RW)										1													
Stephanocolpites costatus (RW)																1							
Bombacacidites sp.										11			1			2	1						
Echipollenites sp.															1								
Echitriporites sp.										1													
Pollen indet.																					2		
Polypodiisporites sp.																	1						
Psilastephanoporites sp.																	1						
Psilatricolporites sp.									1								1						
Retimonocolpites sp.																		1		1			
Retipollenites sp.																		1					
Retisyncolporites sp.																	1						
Retitricolpites sp.			2							1				1		1	1	2					
Retitricolporites sp.														1	2	4	4	1			4		
Stephanocolpate sp.																1							
Verrucatosporites sp.															1								
Verrumonoletes sp.													1										
Verrutriletes sp.														1				1					
Zonotriletes sp.								1												1			

Key to sample code (meters from base of La Paz Formation)

1 =sample UR 376 (-6m.)
2 =sample UR 379 (-4.5m.)
3 =sample UR 395+120 (20.7m.)
4 =sample UR 409+70 (41.2m.)
5 =sample UR 437+5 (83m.)
6 =sample UR 445 (94.5m.)
7 =sample UR 470 (132m.)
8 =sample UR 502 (180m.)
9 =sample UR 507 (187.5m.)
10 =sample UR 531+120 (224.7m.)
11 =sample UR 542+40 (240.4m.)
12 =sample UR 545 (244.5m.)
13 =sample La Paz 361 m (361m.)
14 =sample UR 704+10 (385.1m.)
15 =sample UR 726 (418m.)
16 =sample UR 761 (470.5m.)
17 =sample UR 781+20 (500.7m.)
18 =sample UR 812 (547m.)
19 =sample UR 849 (602.5m)
20 =sample La Paz 712 m (712m)
21 =sample La Paz 886 m (886m)
22 =sample La Paz 989 m (989m)
23 =sample Esm 21 m (1067m)

Table 5-6. First (FAD) and last (LAD) appearance datums and abundace peaks (P) for 84 taxa used in graphic correlation. Units are in meters. Tibui section after Gonzalez(1967), T4 section after Rull (1997b).

	sp.	Piñalerita			Regadera			Uribe		Tibui		T4	
taxon	code	FAD	LAD	P	FAD	LAD	P	FAD	LAD	FAD	LAD	FAD	LAD
Baculamonocolpites "curubensis"	12	696.6	733.7		306			361	361				
Bombacacidites annae	28	30.6	311.4	70							36.8		261.9
Bombacacidites brevis	29	689.4						501	501				
Bombacacidites foveoreticulatus	30	784.8			264	264							
Bombacacidites nacimientoensis	31	660.6	775.6					501	501			485.5	
Bombacacidites soleaformis	32	784.8			128	128							
Brevitricolpites "microechinatus"	36	214.2	214.2			31		225					
Cicatricosisporites dorogensis	42	660.6			264						331.1	326.0	
Cricotriporites "macropori"	56	636.6	775.6			31							
Cricotriporites guianensis	57	475.2	475.2			99		547	547				
Cricotriporites minutipori	58	715.6	715.6										
Curvimonocolpites inornatus	63		105.3										
Cyclusphaera "scabratus"	64	636.6						225					
Echimonocolpites "tenuiechinatus"	67	46.8	266.4										
Echinatisporis "brevispinosus"	71	660.6				128		361	361				
Echinatisporis "microechinatus"	72	673.8	689.4										
Echinatisporis "obscurus"	73	30.6	775.6					712					
Echinatisporis? "cingulatus"	76	733.7	733.7			99		501	547				
Echiperiporites estelae	80	689.4	775.6		306							521.7	680.5
Echitriporites trianguliformis var. "orbicularis"	90	660.6			291	291		501	501	250.7			
Ephedripites vanegensis	93	79.2	131.4								24.5	192.9	261.9
Foveodiporites guianensis	98		5.4										
Foveotricolpites perforatus	100	81	266.4									192.9	261.9
Foveotricolporites "fossulatus"	103	689.4	733.7										
Foveotriporites hammenii	112	660.6	775.6		291	145		547	712	71.2		534.9	
Jussitriporites undulatus	131	660.6	775.6		99	145				187.7			
Ladakhipollenites rubini	133	715.6	738.3										
Ladakhipollenites simplex	134	702.9	710.8		215	215							
Longapertites proxapertitoides var *reticuloides*	149	475.2	775.6	475			31	471	501	240.4	250.7		
L. proxapertitoides var. *proxapertitoides*	150	105.3	696.6	475		145	31	225	471		71.2		

Table 5-6--continued.

taxon	sp. code	Piñalerita FAD	Piñalerita LAD	P	Regadera FAD	Regadera LAD	P	Uribe FAD	Uribe LAD	Tibui FAD	Tibui LAD	T4 FAD	T4 LAD
Momipites africanus	162	30.6	758.6										
Monoporopollenites annulatus	163	636.6	775.6		99	291				229.5		326.0	684.7
Nothofagidites "huertasi"	165	758.6	766.8		264	264							
Perfotricolpites digitatus	170	689.4	715.6							138.4	331.1	521.7	654.0
Perisyncolporites pokornyi	172	660.6			291							286.3	
Polypodiisporites speciosus	181	660.6		753	215			471	547			303.0	
Polysphaeridium sp. A	182	660.6	738.3		291								
Proxapertites cursus	184		702.9					471	471			192.9	247.3
Proxapertites humbertoides	185	30.6	766.8					225	225				261.9
Proxapertites magnus	186		710.8	214		31							531.4
Proxapertites operculatus	187	30.6	775.6	214	264	291		547	547				
Proxapertites psilatus	188	46.8						418	418				
Psilabrevitricolporites simpliformis	193	37	266.4										
Psilamonocolpites grandis	194		311.4										
Psilaperiporites "pauciporatus"	198	660.6	766.8										
Psilastephanocolporites "psilatus"	203	733.7			215	215							
Psilastephanocolporites fissilis	204	673.8	775.6										
Psilastephanoporites "distinctus"	207	733.7	758.6		291								
Psilatricolporites "orbicularis"	213	715.6	715.6		31	31		225	501				
Psilatricolporites "spongiosus"	217	131.4	311.4										
Psilatricolporites crassus	218	660.6			291							384.5	
Psilatricolporites maculosus	219	696.6			215			361	712			367.8	
Psilatricolporites operculatus	220	710.8	710.8									534.9	
Psilatricolporites transversalis	221	234	733.7		99	128							
Psilatricolporites triangularis	222	696.6											
Racemonocolpites facilis	234	636.6						547		23.8	315.9		
Racemonocolpites racematus	235	46.8	46.8					471	471	250.7	331.1		
Retibrevitricolpites "santanderensis"	237	710.8	710.8		145	145							
Retibrevitricolpites triangulatus	240	696.6	710.8					547	547	18.8		445.8	
Retidiporites magdalenensis	245		266.4								27.8		261.9
Retimonocolpites "ovatum"	246	79.2				264		180	712				
Retimonocolpites regio	247		475.2										
Retistephanocolpites angeli	255	46.8	311.4							187.7	321.5	326.0	
Retistephanocolporites festivus	257	689.4			99	128		501	501	36.8	308.6		

Table 5-6--continued.

taxon	sp. code	Piñalerita FAD	Piñalerita LAD	P	Regadera FAD	Regadera LAD	P	Uribe FAD	Uribe LAD	Tibui FAD	Tibui LAD	T4 FAD	T4 LAD
Retistephanoporites angelicus	261	738.3			291					315.9	331.1		
Retitricolpites absolutus	273	738.3	738.3							36.8	282.5		
Retitricolpites antonii	274	696.6	696.6										
Retitricolpites clarensis	275	475.2								240.4			
Retitricolpites florentinus	276	784.8								27.8	308.6		
Retitricolpites magnus	277	660.6	758.6							331.1		521.7	
Retitricolpites saturum	278	196.2	266.4							277.2			
Retitricolporites "delicatus"	282	733.7	752.6		128	128		418	418				
Retitricolporites guianensis	294	660.6										367.8	
Retitricolporites hispidus	295	710.8								71.2	245.0	303.0	
Retitricolporites irregularis	296	636.6			128	291				138.4		286.3	684.7
Retitricolporites mariposus	297	475.2	475.2		128	128							
Retitricolporites medius	298	636.6								36.8			
Rugotricolporites felix	314	689.4	689.4							315.9	331.1	485.5	534.9
Spinizonocolpites "breviechinatus"	329	30.6	266.4										
Spirosyncolpites spiralis	333	636.6				291		180	712	240.4	331.1	286.3	684.7
Striatricolpites catatumbus	336	636.6			99	215		180		315.9		367.8	684.7
Syncolporites lisamae	344	154.8	154.8										247.3
Ulmoideipites krempii	354		266.4			31		225	225				
Verrutricolporites "reticulatus"	360	636.6			291	291							

Table 5-7. Fossil events used in the final Composite Section. Event are in composit units
FAD=first appearance datums, LAD=last appearance datums, peak=abundace peaks.

taxa	code	FAD	LAD	Peak
Baculamonocolpites "curubensis"	12	640	733.7	
Bombacacidites annae	28	30.6	325	
Bombacacidites brevis	29	661		
Bombacacidites foveoreticulatus	30	640		
Bombacacidites nacimientoensis	31	660.6	775.6	
Bombacacidites soleaformis	32	595		
Brevitricolpites "microechinatus"	36	214.2	502	
Cicatricosisporites dorogensis	42	605		
Cricotriporites "macropori"	56	580	775.6	
Cricotriporites guianensis	57	475.2	730	
Cricotriporites minutipori	58	715.6	715.6	
Curvimonocolpites inornatus	63		105.3	
Cyclusphaera "scabratus"	64	565		
Echimonocolpites "tenuiechinatus"	67	46.8	266.4	
Echinatisporis "brevispinosus"	71	640		
Echinatisporis "microechinatus"	72	673.8	689.4	
Echinatisporis "obscurus"	73	30.6	775.6	
Echinatisporis? "cingulatus"	76	680	733.7	
Echiperiporites estelae	80	668		
Echitriporites triangulíformis var. "orbicularis"	90	588		
Ephedripites vanegensis	93	79.2	312	
Foveodiporites guianensis	98		5.4	
Foveotricolpites perforatus	100	81	310	
Foveotricolporites "fossulatus"	103	689.4	733.7	
Foveotriporites hammenii	112	490	791	
Jussitriporites undulatus	131	548	775.6	
Ladakhipollenites rubini	133	715.6	738.3	
Ladakhipollenites simplex	134	625	710.8	
Longapertites proxapertitoides var *reticuloides*	149	475.2	775.6	475.2
Longapertites proxapertitoides var. *proxapertitoides*	150	105.3	696.6	475.2
Momipites africanus	162	30.6	758.6	
Monoporopollenites annulatus	163	568		

taxa	code	FAD	LAD
Psilabrevitricolporites simpliformis	193	37	266.4
Psilamonocolpites grandis	194		311.4
Psilaperiporites "pauciporatus"	198	660.6	766.8
Psilastephanocolporites "psilatus"	203	625	
Psilastephanocolporites fissilis	204	673.8	775.6
Psilastephanoporites "distinctus"	207	650	758.6
Psilatricolporites "orbicularis"	213	505	715.6
Psilatricolporites "spongiosus"	217	131.4	311.4
Psilatricolporites crassus	218	637	
Psilatricolporites maculosus	219	621	
Psilatricolporites operculatus	220	705	710.8
Psilatricolporites transversalis	221	232	733.7
Psilatricolporites triangularis	222	696.6	
Racemonocolpites facilis	234	265	
Racemonocolpites racematus	235	46.8	715
Retibrevitricolpites "santanderensis"	237	600	710.8
Retibrevitricolpites triangulatus	240	245	
Retidiporites magdalenensis	245		312
Retimonocolpites "ovatum"	246	79.2	
Retimonocolpites regio	247		475.2
Retistephanocolpites angeli	255	46.8	685
Retistephanocolporites festivus	257	322	
Retistephanoporites angelicus	261	650	
Retitricolpites absolutus	273	322	738.3
Retitricolpites antonii	274	696.6	696.6
Retitricolpites clarensis	275	475.2	
Retitricolpites florentinus	276	265	
Retitricolpites magnus	277	660.6	758.6
Retitricolpites saturum	278	196.2	266.4
Retitricolporites "delicatus"	282	590	752.6
Retitricolporites guianensis	294	650	
Retitricolporites hispidus	295	490	

Table 5-7--continued.

taxa	code	FAD	LAD	Peak
Nothofagidites "huertasi"	165	640	766.8	
Perfotricolpites digitatus	170	522	780	
Perisyncolporites pokornyi	172	612		
Polypodiisporites specious	181	615		
Polysphaeridium sp. A	182	650	738.3	
Proxapertites cursus	184		702.9	
Proxapertites humbertoides	185	30.6	766.8	
Proxapertites magnus	186		725	214.2
Proxapertites operculatus	187	30.6	775.6	214.2
Proxapertites psilatus	188	46.8		
Retitricolporites irregularis	296	522		
Retitricolporites mariposus	297	475.2	475.2	
Retitricolporites medius	298	322		
Rugotricolporites felix	314	665	725	
Spinizonocolpites "breviechinatus"	329	30.6	266.4	
Spirosyncolpites spiralis	333	560		
Striatricolpites catatumbus	336	562		
Syncolporites lisamae	344	154.8	255	
Ulmoideipites krempii	354		610	
Verrutricolporites "reticulatus"	360	580		

Table 5-8. Datums used for calibration of Composite Section. Rio=Paz de Rio section, rubio= Rubio section, Imo=Imo section; Ovim= Ovim section, Benin=Benin well (Germeraad *et al* ., 1968) Itori=Itori well (Agegoke *et al.* , 1970, Jan du Chene *et al.* , 1978)

	Rio			Rubio		Imo		Benin		Ovim		Itori	
taxa	code	FAD	LAD	FAD	LAD	FAD	LAD	FAD	LAD	FAD	LAD	FAD	LAD
Bombacacidites annae	28			57.7	469.2								
Cicatricosisporites dorogensis	42	469.2		746.2				3980	2495				
Echiperiporites estelae	80	496.2											
Foveotricolpites perforatus	100	92.3	92.3	57.7	469.2								
Monoporopollenites annulatus	163	469.2		638.5	730.8	576	2010	5085		1095			
Perfotricolpites digitatus	170	469.2								1550			
Perisyncolporites pokornyi	172	469.2		746.2		704	704			1030	1030		
Proxapertites cursus	184	92.3	188.5		469.2	192	2010			675			
Proxapertites operculatus	187	92.3					2010		4025	225			
Psilatricolporites crassus	218	496.2	888.5	584.6	738.5	768		4805		450			
Psilatricolporites operculatus	220	469.2				2320		4096					
Retibrevitricolpites triangulatus	240	496.2	719.2	530.8	746.2	576	2010		3420	450		16.5	13.0
Retidiporites magdalenensis	245				407.7		384				225		13.0
Retitricolporites guianensis	294			746.2									
Retitricolporites irregularis	296	469.2		530.8	696.2								
Striatricolpites catatumbus	336	361.0		530.8	730.8	192		5085		450			

Nigeria and contained sporomorph information and radiometric dating of a bentonite (Adegoke *et al.*, 1970; Jan du Chêne *et al.*, 1978a). Datums for this section are in Table 5-8. These four sections were compared against the Composite Section (CS). The planktonic datums and radiometric age were then projected upon the CS (Fig. 5-14, 5-15, and 5-16).

Discussion

Biostratigraphers should not expect widespread synchronous first and last occurrences in the stratigraphic record. Many variables like migration, non preservation, barriers, and local extinctions can truncate the geological range of a taxon (Mann and Lane, 1995). Pollen and spores distributions in tropical environments are strongly controlled by the geographic distribution of the plants from which they are coming. However, this fact has not been considered in the palynological zonations proposed so far for the Paleocene-Eocene interval in northern South America. For example, some zones have been based on pollen produced by mangrove elements (*Psilatricolporites crassus* zone, Germeraad *et al.,* 1968). A zone like that clearly would be controlled by facies, and would lead to the recognition of false "hiatus" in continental areas where mangrove was not present. This may be one of the reasons of the multitude of hiatus proposed during the Eocene in the Colombian-Venezuela region (Colmenares and Terán, 1993). Here, the pollen and spores distribution was analyzed using the technique of graphic correlation. This method dismisses narrative-type scenarios and produces alternative hypothesis that can be expressed in testable forms (Mann and Lane, 1995). Graphic correlation does not make the *a priori* assumption that first and last appearances in a particular section record speciation and extinction events. By combining the information of multiple sections, the method allows the true stratigraphic range of a taxon to be determined; therefore, the use of an "index" fossil is not necessary as the whole assemblage is being compared. This approach also produces a biostratigraphic framework that constantly can be challenged as

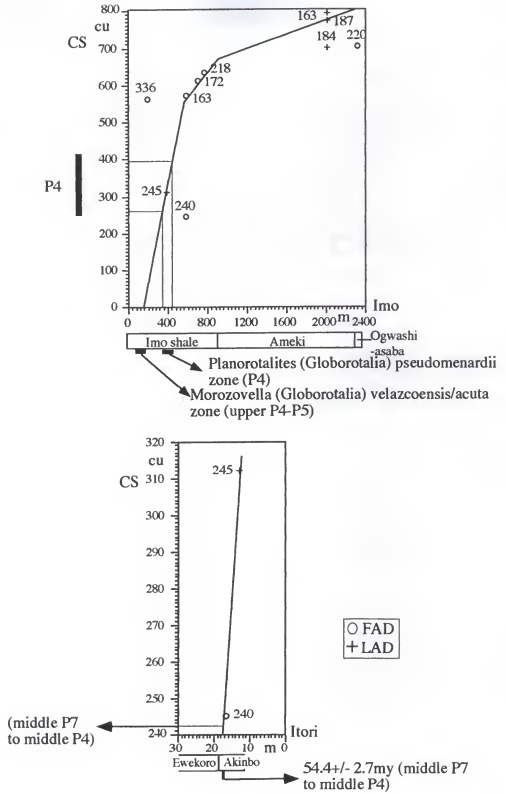


Figure 5-14. Line of correlation for Imo section (Germeraad *et al.*, 1968) and Itori well (Adegoke *et al.*, 1970 and Jan du Chene *et al.*, 1978) versus Composite Section. See Table 5-6 for names of the taxa used in graphic correlation.

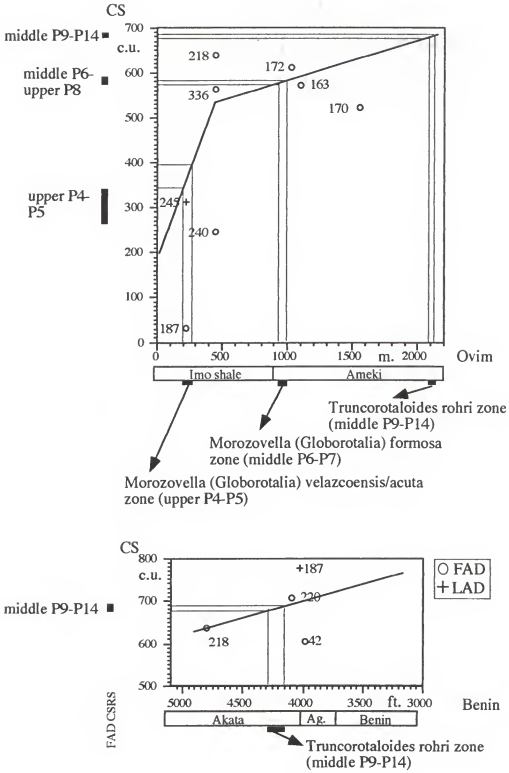


Figure 5-15. Line of correlation for Ovim and Benin section (Germeraad *et al.*, 1968) versus Composite Section. See Table 5-6 for names of the taxa used in graphic correlation.

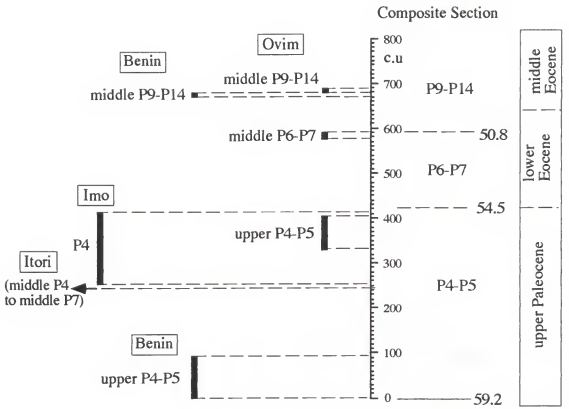


Figure 5-16. Summary of calibration datums for the Composite Section. See Figures 5-14 and 5-15 for source of information.

new information (more sections) is being produced. On the contrary, "traditional" zonations such as the ones currently used in northern South America, are static and authoritative, strongly relying opon one biostratigrapher's interpretation of the chronostratigraphic importance of a given taxa. Graphic correlation was developed by Shaw (1964) and has been successfully used for many authors and specially by Amoco researchers for many years (Carney and Pierce, 1995).

The general sequence of events, first appearance datums (FAD), last appearance datums (LAD), and abundance peaks, of the Composite Section (CS) is similar to those of previous zonations (Table 5-7 for datums, c.u. indicates composite unit). The sequence of *Foveotricolpites perforatus* LAD (81 composite units c.u.); *Retibrevitricolpites triangulatus* FAD (245 c.u.); *Foveotricolpites perforatus* LAD (310 c.u.); *Ephedripites vanegensis* LAD (312 c.u.); *Retidiporites magdalenensis* LAD (312 c.u.); *Bombacacidites annae* LAD (325 c.u.); *Cricotriporites guianensis* LAD (475.2 c.u.); *Foveotriporites hammeni* FAD (490 c.u.); *Monoporopollenites annulatus* FAD (568 c.u.);*Cicatricosisporites dorogensis* FAD (605 c.u.); *Perisyncolporites pokornyi* FAD (612 c.u.); *Psilatricolporites crassus* FAD (637 c.u.); and *Rugotricolpites felix* LAD (725 c.u.) mostly agrees with previous zonations.

However, there are several discrepancies with Germeraad *et al.* (1968) and Muller *et al.* (1987) zonations specially within the Eocene. Taxa, which according to these zonations should not be overlapping, are overlapped (e.g., *Cicatricosisporites dorogensis* and *Rugotricolpites felix*). Most of the taxa ranges in Muller's and Germeraad's zonations abruptly end or begin at time boundaries (Paleocene/Eocene, lower/middle Eocene, and middle/late Eocene). In the Composite Section (CS), the first and last occurrence events are tied to stratigraphy. This produces a higher time resolution and non-congruence in single stratigraphic horizons of most of the first appearance datums (FAD) and last appearance datums (LAD). Therefore, many of the FAD and LAD sequence of events in the CS do not agree with the Germeraad *et al.* (1968) and Muller *et al.* (1987) zonations

where taxa appear in pseudo-bursts of speciation events (e.g., Paleocene/Eocene boundary with 25 new taxa). This probably is also helped by the higher level of resolution of the CS versus previous zonations. It is also noteworthy the increasing of first occurrence datums above 550 c.u. (probably Eocene, see discussion below) that had been noted already by many authors (Leidelmeyer, 1966; Gonzalez, 1967).

The CS has low sample resolution between 330 and 390 c.u. and between 500 and 600 cu. due to the sterility of most of the samples in the Piñalerita section (upper Arcillas de El Limbo, lower Areniscas de El Limbo Formations), in the Regadera section (upper Cuervos, lower Mirador), and in the Uribe section (upper Lisama, lower La Paz Formations, see Tables 5-3, 5-4, and 5-5). Information for this interval, however was supplied by Tibui section (Gonzalez, 1967). Correlations of these sections against the composite (Figs. 5-11, 5-12), indicate that there is not a significant hiatus associated with the Mirador/Cuervos, La Paz/Lisama, or Arcillas de El Limbo/Areniscas de El Limbo contacts, at least in the localities studied. Many authors since the fifties have associated this contact in Colombia with a major hiatus that would encompass 16 my, the entire early to middle Eocene (Morales, 1958; Schamel, 1991; Dengo and Covey, 1993; Cooper *et al.*, 1995; Ramon and Cross, 1997; Suarez, 1997a; Suarez, 1997b; Villamil and Restrepo-Pace, 1998). This idea is deeply rooted in Colombian literature and nowadays constitutes a "pseudo-dogma". However, an intensive literature search has not given even a single locality with fully documented paleontological information supporting this hypothesis, some localities with palynological information have not registered this hiatus (Gonzalez, 1967 in Catatumbo area, and Colmenares and Terán, 1993 in Maracaibo Basin). It could be possibly that in the files of oil companies exist enough evidence supporting this hiatus; however, the graphic correlation of the three sections studied and the Tibui, Rubio and Paz de Rio sections (Figs. 5-11 to 5-13) does not indicate a major hiatus encompassing 16 my. Julivert (1961) also pointed out the lack of paleontological evidence supporting this hiatus in the middle Magdalena area and conclude that the time-

gap, where present, would be isochronous with the accumulation of the Lisama Formation (Paleocene), because Lisama is absent from anticlines axis, and in angular unconformity above Cretaceous sediments in anticline flanks. The time-gap would not be between La Paz-Lisama as previously assumed but during the accumulation of Lisama. I would argue that one of the reasons that is producing the perception of this hiatus is that samples above and below the assumed hiatus are generally sterile for palynomorphs. This would produced an artificial gap in time because of the absence of traditional pollen zones present within the sampling gap. The possibility of an important hiatus is, however, still an open question.

One of the most difficult tasks in biostratigraphy is calibrating the Composite Section (CS) with the geologic time scale. The Paleocene and Eocene epochs and their ages are defined by planktonic foraminifera, calcareous nannoplankton and magnetic polarities. The chronostratigraphy of Berggren *et al.* (1995b) for the late Paleocene and Eocene is followed here (Fig. 5-17). The planktonic foraminifera zonation is that of Berggren *et al.* (1995b). Most of the epoch/series and stage/age boundaries of the late Paleocene and Eocene are relatively well established with the exception of the Paleocene/Eocene boundary that still does not have a Global Stratotype Section and Point (GSSP). The Paleocene and Eocene series terms were defined in 1874 and 1833 respectively (Berggren and Aubry, 1998). The boundary awaits determination of a GSSP within the 2 my time span between the top of the Thanetian Stage and the base of the Ypresian Stage. The difficulties in defining the boundary are caused by the multitude of unconformities and facies changes at the base of the type section of Ypresian Stage in Belgium (base of Ieper Clay of the Belgian Basin that is equivalent to base of the London Clay Formation in London/Hampshire Basin). The base of the Ypresian Stage/Series in these two localities is separated from top of Thanetian Stage/Series (Thanet Beds, London Basin) by an stratigraphic interval where Paleocene/Eocene boundary would be located (Berggren and Aubry, 1998). This interval encompasses from NP10a/b

boundary, base of Ypresian (54.37 my) to the top of Thanetian (56.6 my). Several events within this interval are suggested to denote the Paleocene/Eocene boundary (Berggren and Aubry, 1998). Planktonic P5/P6 boundary (54.48 my), N9/N10 boundary (55 my), benthic foraminiferal extinction (55.5 my), and delta^{13}C isotopic excursion (55.5 my). Here, the planktonic P5/P6 boundary (54.48 my) is chosen as the Paleocene/Eocene boundary (Fig. 5-17).

Few elements are available to calibrate the CS. Germeraad *et al.* (1968) paper stated a number of foraminifera taxa recorded from sections in Colombia and Venezuela (see Fig. 5-2 and text in "previous studies"). Unfortunately, the paper did not indicated the precise stratigraphic position of any of those foraminifera taxa. Therefore, they cannot be used in the graphic correlation methodology. Germeraad *et al.* (1968) only presented stratigraphic positions of foraminifera from sections in Nigeria. These were the information used to calibrate the CS developed in this study. Germeraad *et al.* (1968) and subsequent reaearch in Nigeria (Adegoke and Jan du Chene, 1975; Jan du Chêne and Salami, 1978; Jan du Chêne *et al.*, 1978a; Salami, 1985; Awad, 1994) have noticed floristic similarities between northern South-America and tropical Africa during Paleocene and Eocene times. These authors also have used, to some extent, the Germeraad *et al.* (1968) zonation. Therefore, correlations with the Nigerian sections probably would provide a general idea of the timing of pollen and spores succession in northern South America until further research in the area is done.

The Imo and Ovim sections contain the *Planorotalites (Globorotalia) pseudomenardii* zone that is equivalent to P4 zone of Berggren *et al.* (1995b), and the *Morozovella velascoensis/Morozovella acuta* zone that is equivalent to the upper P4 to P5 zones of Berggren *et al.* (1995b) (see Figs. 5-14, 5-15 and 5-16; taxonomy after Tourmankine and Luterbache, 1985, taxa ranges after Tourmankine and Luterbache, 1985 and Berggren *et al.*, 1995b). When projected in the CS, the foraminifera indicate that the interval P4-P5 is located between composite units (c.u.) 0 to 410 (Fig. 5-16). The

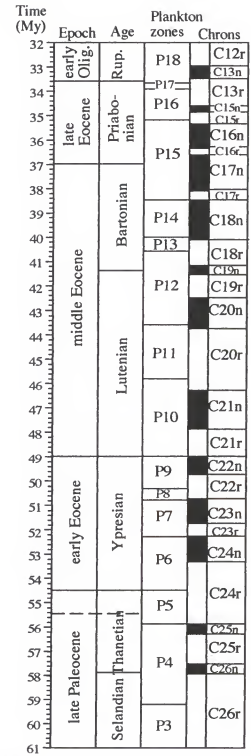


Figure 5-17. Berggren *et al.* (1995) chronology of the late Paleocene-Eocene epochs. Dashed lines at 55.5 My reflects current opinion on the position of the Paleocene-Eocene boundary. Taken at the base of the type Ypresian in Belgian basin or the London Clay in London Basin it position would be at 54.6 to 54.8My.

position of the Paleocene/Eocene boundary is then tentatively located at c.u. 420, although it could be located in an interval between 410 and 475, because the sample at 477 meters in the Piñalerita section (c.u. 475) contains an assemblage that lack typical late Paleocene taxa as *Foveotricolpites perforatus*, *Retidiporites magdalenensis*, and *Bombacacidites annae*. This late Paleocene age given to the 0-410 c.u., is also supported by the radiometric dating of a bentonite (Adegoke *et al.*, 1970; Jan du Chêne *et al.*, 1978a) that yielded an age of 54.4+/- 2.7 million years equivalent to middle P7 to middle P4 planktonic zones (Figs. 5-14, 5-17).

The early Eocene is recognized by the projection in the CS of the *Morozovella formosa* zone of Germeraad *et al.* (1968). They did not state how this zone was identified, therefore, I took the conservative approach of considering the total range of *M. formosa-formosa*, (middle P6 to P7 after Berggren *et al.*, 1995b), as the chronostratigraphic significance of Germeraad *et al.* (1968)*M. formosa* zone (Fig. 5-17). Therefore, the early Eocene (zones P5 to P7) would be represented between composite units 420 to 590 (Fig. 5-16).

The uppermost early Eocene and middle Eocene is recognized by the Germeraad *et al.* (1968) *Truncorotaloides rohri* zone. They did not state how this zone was recognized, therefore here I take the conservative approach of considering the whole range of *T. rohri* (middle P9 to P14 after Tourmankine and Luterbache, 1985) to denote the chronostratigraphic significance of the "*T. rohri* zone". In this scenario the latest early Eocene and middle Eocene would be present above 590 up to 670 c.u. Calibration above 670 c.u. is not possible due to the lack of foraminifera data.

An alternative hypothesis would be to consider the *T. rohri* of Germeraad equivalent to *T. rohri-M. spinulosa* Partial Range Zone (P14) of Berggren *et al.* (1995b). This hypothesis would indicate an extensive time condensation (~10.8 my), between c.u. 590 and 670, top of P7 to base of P14 (see Figure 5-16). This condensation, however, is not supported by the stratigraphic position of this composite unit (c.u.) level in Uribe,

Regadera, Tibui, T1 sections (Figs. 5-11 and 5-12, Appendix B), where lithology does not indicate an extensive hiatus. This level in the Piñalerita section is associated with a transgressive surface (see discussion in Sequence Stratigraphy below) and probably some time condensation (Fig. 5-12). Therefore, the possibility of an early to middle Eocene hiatus still exists but further research is necessary to address this specific issue.

CHAPTER 6
SEQUENCE STRATIGRAPHY

Sequence stratigraphic is the study of genetically related facies within a framework of chronostratigraphic significant surfaces (Van Wagoner *et al.*, 1990). The "sequence" is its basic unit that is defined as a relatively conformable, genetically related succession of strata bounded by unconformities or their relative conformities (Van Wagoner *et al.*, 1990). A parasequence is the building block of a sequence and is defined as a relatively conformable, genetically related succession of beds or bedsets bounded by marine-flooding surfaces or their correlative surfaces (Van Wagoner *et al.*, 1990).

A sequence stratigraphic analysis requires many different types of information (sedimentary, biostratigraphic, seismic) to fully understand the stacking pattern of parasequences in lowstand systems tract (LST), transgressive systems tract (TST); or highstand systems tract (HST), and the recognition of important surfaces (MFS: maximum flooding surface, TS: transgressive surface, and SB: sequence boundary). In this study, I combined three different types of information (palynofacies, paleoecological analysis of palynomorphs, and lithological analysis) to produce a "paleobathymetric" curve (a curve that represents the relative movement of the coastline in relation to a fixed point that is the section studied), and a sequence stratigraphic interpretation for each of the three sections. In the following headings (Palynofacies, Paleoecology, and Lithology), I will present and discuss each type of information. At the end of this chapter (in "Sequence Stratigraphic Interpretation"), they will be combined and a sequence stratigraphic model will be proposed for each stratigraphic section. This analysis does not include a reconstruction of the regional geometry of the entire basin. The purpose here is to produce well-supported stratigraphic hypothesis, with age control, that can be

used to test previous sequence stratigraphic models and can be used in the future as reference points. One of the most problematic issues in the Paleogene geology of Colombia is the lack of well-supported models (age, environment, sequence stratigraphy) for individual sections. Most of the published work consists of regional summaries and models without well-documented data, especially lacking paleontologic data, supporting those interpretations (e.g., see Cooper *et al.*, 1995). The other major problem hampering a clear understanding of Tertiary stratigraphy of Colombia has been the lack of stratigraphic nomenclatural consistency that has lead to naming a formation with several names, or different formations with the same name (Porta, 1974). Correlations are often done based on lithology and formational names sometimes creating stratigraphic chaos (Porta, 1974).

One of the biggest misconceptions about sequence stratigraphy is that one must accept the validity of eustatic sea level curves (Haq *et al.*, 1988) to use sequence stratigraphy. However, as Weimer and Posamentier (1994) pointed out: "regardless of whether one accepts or rejects the published global curves, it is important to realize that this debate does not affect the other major, and much more important, aspect of sequence stratigraphy: i.e., lithology prediction". Stratum hierarchy and distribution predicted by sequence stratigraphic models are produced in response to variations of relative sea level rather than solely eustatic changes. Therefore, the sequence stratigraphy model will apply whether or not eustasy is driving the generation of space available for accumulation of sediments through time.

Palynofacies

Previous Studies

Palynofacies is defined here as the microscopic organic constituent of a rock (Combaz, 1964). Palynofacies analyses have been used in many studies to identify depositional environments (Batten, 1973; Hart, 1986) and in sequence stratigraphic

analysis (Batten, 1973; Hart, 1986; Gregory and Hart, 1992; Blondel *et al.*, 1993; Habib *et al.*, 1994; Jaramillo and Oboh, 1999). Important factors controlling the distribution and preservation of particulate organic matter are energy in the area of deposition, water table position, and the oxidation potential of the water-sediment interface (Batten, 1973; Hart, 1986; Lorente, 1986; Batten, 1996). Higher levels of oxygenation of the sediment-water interface increase the degradation of organic matter while anoxia preserves particles and its internal structures (Lorente, 1986; Batten, 1996). Other factors as climate and microclimate, local and regional vegetation, water characteristics, soil biota, and sedimentation rate also affect the composition of the palynofacies. However, several trends can be identified along the fluvial-coastal-nearshore environmental gradient. These trends can be used to identify shifting depositional environments through time (Lorente, 1986; Jaramillo and Oboh, 1999).

Few studies specifically addressing palynofacies analysis are available from tropical regions, where vegetation types are different and rates of degradation of organic matter are higher (Batten, 1996). Lorente (1986; 1990) in a pioneer work for palynofacies from tropical regions, developed a number of models for fluvio-deltaic and nearshore environments in the Orinoco delta. Muller (1959) also studied the Orinoco delta only focusing on the pollen, spore, and dinoflagellate distributions. Risks and Rhodes (1985) studied palynofacies of mangrove environments in tropical Australia; Bustin (1988) studied the palynofacies of the Tertiary of Niger delta; Van Waveren and Visscher (1994) studied the organic matter of surficial deep-sea sediments in Banda Sea, Indonesia; and Gastaldo *et al.* (1996) and Gastaldo and Staub (1997) studied palynofacies of modern sediments in the Rajang river and delta in Malaysia.

Results

The results for the point count of organic matter particles are shown in Tables 6-1, 6-2, and 6-3. Using the thickness of each stratigraphic section as scale, the relative

frequencies of the organic matter types in the three sections were plotted in Figures 6-1, 6-2 and 6-3.

Euclidean-distance cluster analysis for the Piñalerita section identified six groups of samples on the basis of their organic matter content (Figs. 6-4, 6-5). Group 1 is characterized by a high dominance (more than 60%) of black debris. Group 2 is characterized by a dominance of yellow brown plus black brown, plant tissue and sporomorphs. Group 3 is characterized by a codominance of plant tissue and black brown, with occasionally high abundance of sporomorphs and dinoflagellates. Group 4 of samples are codominated by black debris and black brown. Group 5 is dominated by plant tissue with moderate abundances of dinoflagellates and sporomorphs. Group 6 is characterized by yellow brown organic matter. There is not a strong correlation between sample lithology and palynofacies content (see lithofacies and cluster groups in Figure 6-4). Similar lithofacies, therefore, could produce different palynofacies.

The organic matter data from the Regadera and Uribe sections were combined into a single analysis because they were probably accumulated in similar environments (Notestein *et al.*, 1944; Porta, 1974). Therefore, organic matter could be distributed in a similar way across the diverse subenvironments of the fluvial environment. The Euclidean-distance cluster analysis for the Regadera and Uribe sections identified five groups of samples on the basis of their organic matter content (Figs. 6-6, 6-7). Group A is dominated mainly by yellow brown organic matter. Group B is characterized by high percentages of plant tissue, with moderate abundances of sporomorphs and black debris. Group C is dominated by black brown with moderate abundances of yellow brown and black debris. Occasionally moderate abundances of sporomorphs are present. Group D is dominated by black debris with moderate concentrations of plant tissue and black brown. Group E is characterized by a total dominance of black debris. There is not a strong correlation between sample lithology and palynofacies content (see lithofacies and

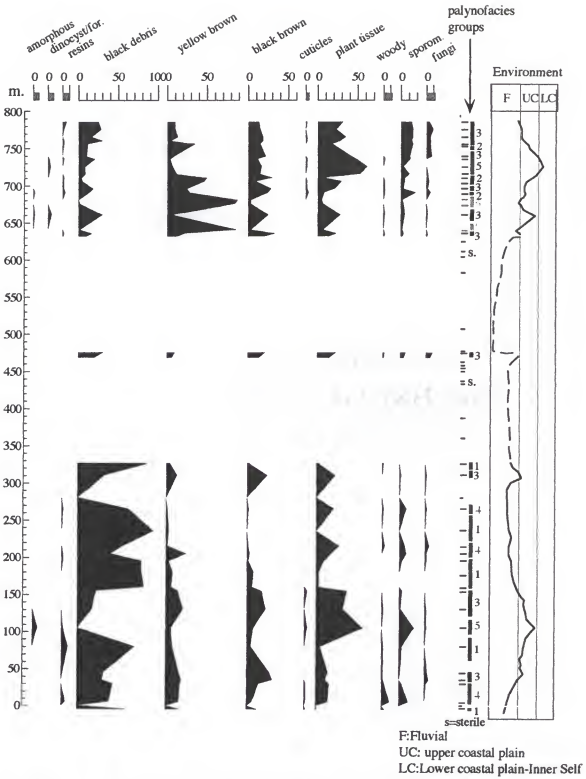


Figure 6-1. Palynofacies of Piñalerita section showing abundances of each organic matter type, palynofacies groups from cluster analysis, and paleoenvironmental interpretation

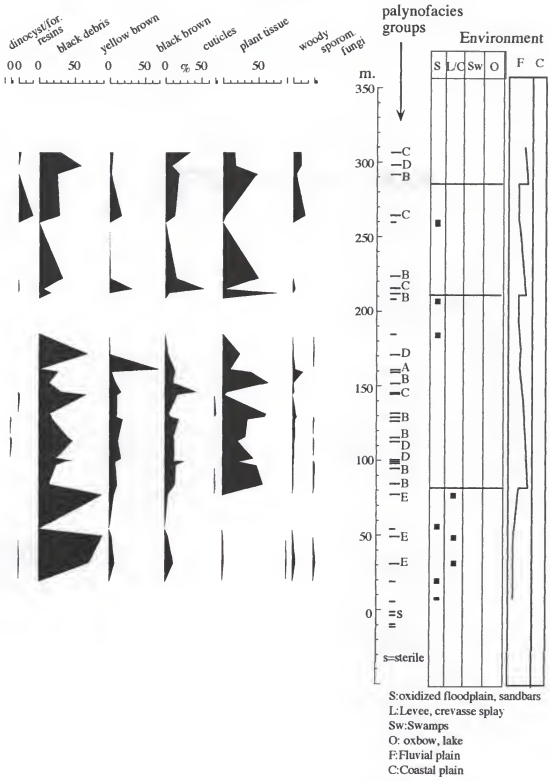


Figure 6-2. Palynofacies of Regadera section showing abundances of each organic matter type, palynofacies groups from cluster analysis, and paleoenvironmental interpretation

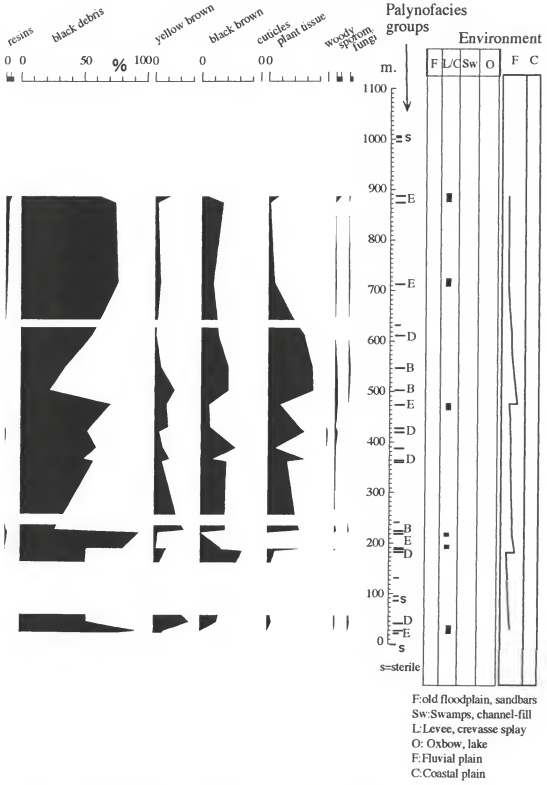


Figure 6-3. Palynofacies of Uribe section showing abundances of each organic matter type, palynofacies groups from cluster analysis, and paleoenvironmental interpretation.

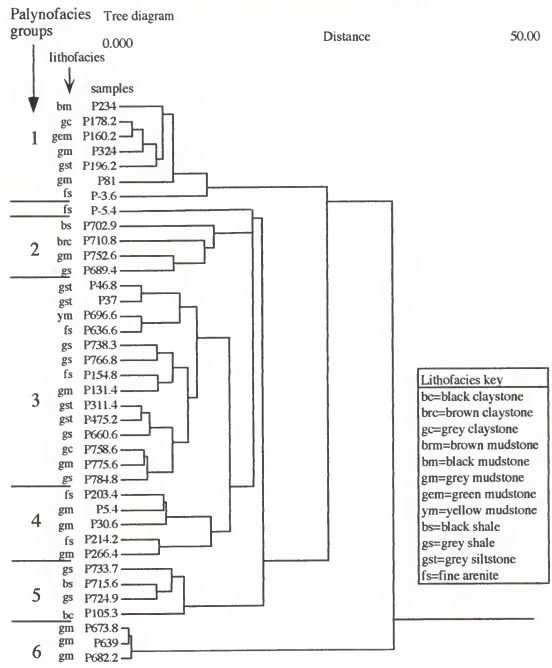


Figure 6-4. Average linkage cluster analysis (with Euclidean distance) of palynofacies in the Piñalerita section. Each palynofacies group represents a group of samples with similar organic matter content, which accumulated in a similar environment. Lithofacies for each sample is provided

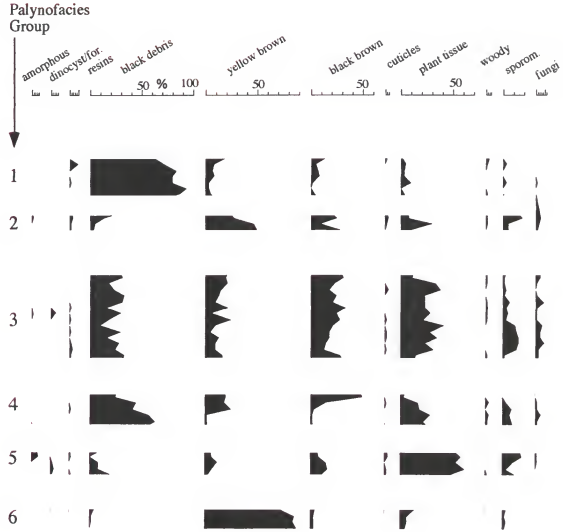


Figure 6-5. Organic matter content of each of palynofacies group identified by Euclidean cluster analysis of Figure 6-4 for Piñalerita section.

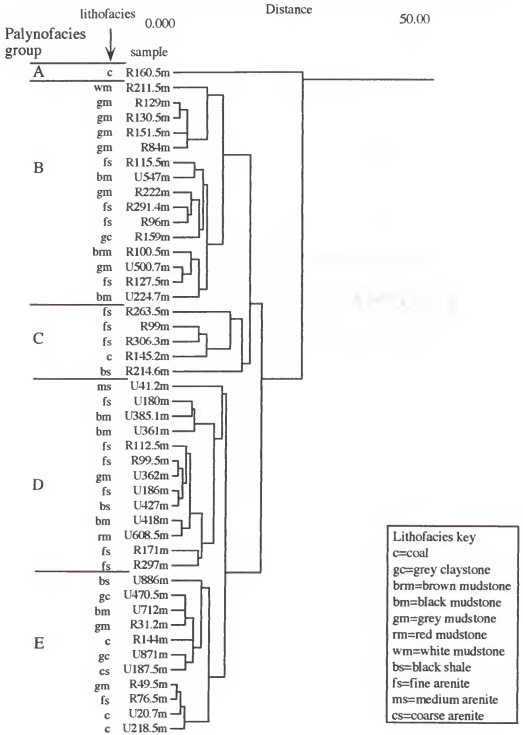


Figure 6-6. Average linkage cluster analysis (with Euclidean distance) of dispersed organic matter in the Regadera and Uribe sections. Each palynofacies group represents a group of samples with similar organic matter content, which accumulated in a similar environment. Lithofacies for each sample is provided.

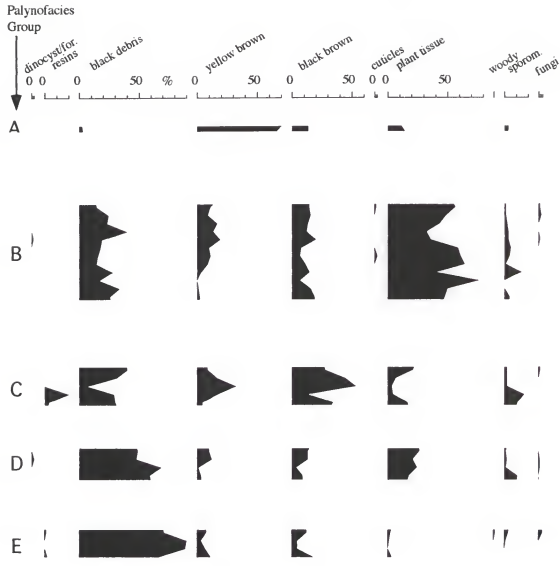


Figure 6-7. Organic matter content of each of palynofacies group identified by Euclidean cluster analysis of Figure 6-6 for Regadera and Uribe sections.

Table 6-1. Palynodebris count data (in %) for the Piñalerita section. Meters from base Arcillas de El Limbo Formation
Organic matter categories are described in Table 1.

Sample		Aquatic		Terrestrial								
number	meters	amorphous	dinocyst	resins	black debris	yellow brown	black brown	cuticles	plant tissue	woody	sporom.	fungi
NA -2	-5.4	0.0	0.2	0.0	24.7	20.6	50.7	0.2	3.2	0.2	0.2	0.0
NA -1	-3.6	0.0	0.0	0.3	63.8	17.8	13.1	1.1	0.9	2.3	0.3	0.3
N 0+60	-1.2	Barren										
N 4	5.4	0.0	0.0	3.2	40.8	16.3	6.1	0.8	14.5	5.8	12.1	0.5
N 18	30.6	0.0	0.3	0.3	44.7	17.7	14.2	0.6	16.0	2.0	3.7	0.6
N 21 +100	37	0.0	0.3	0.0	32.2	20.6	31.6	0.0	11.3	0.6	0.8	2.5
N 27	46.8	0.0	0.3	0.6	33.5	17.2	29.1	0.0	15.2	0.8	1.7	1.7
NA 46	81	0.3	0.0	5.0	71.2	8.0	5.5	0.0	5.8	0.8	3.3	0.0
NA 59+90	105.3	3.7	0.3	0.9	0.6	6.2	8.7	1.6	57.9	0.0	19.0	0.9
N 74	131.4	0.0	0.0	0.3	17.5	21.2	24.0	0.0	33.4	0.6	1.7	1.4
N 87	154.8	0.0	0.0	0.3	22.9	15.7	18.6	1.9	37.5	0.3	2.9	0.0
N 90	160.2	0.0	0.0	0.0	83.0	6.9	6.2	0.0	3.0	0.3	0.7	0.0
N 100	178.2	0.0	0.0	0.0	80.6	8.2	7.6	0.0	2.6	0.3	0.7	0.0
N 110	196.2	0.0	0.0	1.0	80.1	2.8	1.3	0.0	9.8	0.0	4.1	0.8
N 114	203.4	0.0	0.0	0.9	41.5	25.5	4.0	0.3	18.1	0.3	8.6	0.9
N 120	214.2	0.0	0.0	0.0	57.1	1.7	2.0	0.0	28.9	1.7	6.0	2.7
N 131	234	0.0	0.0	0.0	94.2	3.9	0.8	0.0	0.8	0.3	0.0	0.0
N 149	266.4	0.0	0.0	0.5	63.6	1.9	1.4	0.0	22.2	1.2	8.4	0.7
N 157	280.8	Sterile										
N 174	311.4	0.0	0.0	0.0	34.1	14.1	25.0	0.3	24.0	0.3	1.6	0.8
N 181	324	0.0	0.0	0.0	86.3	5.5	4.1	0.0	3.2	0.9	0.0	0.0
N 201	360	Sterile										
N 216	387	Sterile										
N 241	432	Sterile										
N 254	455.4	Sterile										
N 265	475.2	0.0	0.0	0.3	31.8	10.6	21.8	0.0	23.5	0.6	6.0	5.4
N 265+150	476.7	Sterile										
N 283	507.6	Sterile										
N 325	583.2	Sterile										
N 349	626.4	Sterile										

Table 6-1--continued.

Sample	Aquatic		Terrestrial									
number	meters	amorphous	dinocyst	resins	black debris	yellow brown	black browr	cuticles	plant tissue	woody	sporom.	fungi
N 354+120	636.6	0.0	0.0	0.8	16.2	22.3	32.6	0.0	23.1	0.6	3.3	1.1
PIN 0	639	0.0	0.0	0.0	1.7	86.2	4.0	0.0	6.9	0.0	1.1	0.0
PIN 12	660.6	0.6	3.2	0.0	30.2	6.7	24.4	0.0	28.2	0.9	4.7	1.2
PIN 19+60	673.8	0.0	0.0	0.0	2.0	84.2	3.9	0.0	5.9	0.0	3.9	0.0
PIN 24+90	682.2	0.0	0.0	0.0	0.6	88.9	3.5	0.0	5.3	0.0	1.8	0.0
PIN 28+0	689.4	0.9	0.0	1.9	12.7	28.2	25.4	1.9	7.5	0.9	17.8	2.8
PIN 32+0	696.6	0.0	0.0	0.6	18.3	24.2	28.6	1.2	21.2	1.2	4.1	0.6
PIN 35+90	702.9	0.0	0.0	0.9	4.7	47.0	9.5	0.6	30.0	0.9	4.7	1.6
PIN 39+166	710.8	0.0	0.0	0.7	3.9	50.5	30.2	0.3	8.5	0.3	4.9	0.7
PIN 42+100	715.6	0.0	0.6	0.0	8.0	11.8	14.9	0.3	52.9	0.3	10.2	0.9
PIN 47+100	724.9	0.0	2.2	0.0	8.8	7.1	15.9	0.9	61.3	0.0	3.5	0.2
PIN 52+110	733.7	0.3	0.6	0.6	19.2	4.0	12.1	0.6	48.6	1.2	12.4	0.3
PIN 55+30	738.3	0.0	0.3	0.3	9.3	9.6	22 3	0.3	41.5	0.3	12.3	3.7
PIN 63+20	752.6	0.0	0.0	1.0	11.3	35.2	15.0	0.3	18.3	0.3	15.6	3.0
PIN 66+80	758.6	0.0	0.0	1.2	29.6	4.9	18.8	0.6	28.4	0.0	13.6	2.9
PIN 71+10	766.8	0.0	0.0	0.0	16.1	13.4	18.1	0.7	34.8	0.0	14.4	2.7
PIN 75+160	775.6	0.0	0.0	0.6	28.9	10.6	15.5	0.0	23.6	0.0	15.5	5.3
PIN 81+0	784.8	0.0	0.3	2.5	25.5	10.3	13.1	0.9	31.2	0.0	14.0	2.2

Table 6-2. Palynodebris count data (in %) for the Regadera section. Meters from base of Mirador Formation. Organic matter categories are described in Table 1.

Sample		Aquatic			Terrestrial							
number	meters	amorphous	dinocyst	resins	black debris	yellow brown	black brown	cuticles	plant tissue	woody	sporom.	fungi
RE 39	-12.0	Sterile										
RE 40	-10.5	Sterile										
RE 44 + 100	-4.5	Sterile										
RE 46	-1.5	Sterile										
RE 49+130	4.3	Sterile										
RE 59	18.0	Sterile										
RE 67+120	31.2	0.0	0.0	0.6	70.7	7.7	11.9	0.0	1.9	0.3	3.9	2.9
RE 80 + 120	49.5	0.0	0.0	0.0	89.5	3.2	4.8	0.0	1.6	0.0	1.0	0.0
RE 83	54.0	Sterile										
RE 98	76.5	0.0	0.0	0.0	89.1	6.6	4.4	0.0	0.0	0.0	0.0	0.0
RE 103 + 130	84.0	0.0	0.0	0.3	14.3	11.1	14.7	0.7	57.0	0.0	1.3	0.7
RE 111	96.0	0.0	0.0	0.0	24.7	8.7	15.3	0.0	48.3	0.0	1.3	1.7
RE 113	99.0	0.0	0.0	0.3	39.6	8.6	27.5	0.0	20.7	0.0	2.1	1.2
RE 113 + 50	99.5	0.0	0.0	0.0	48.9	10.0	13.3	0.0	26.5	0.0	1.3	0.0
RE 114	100.5	0.0	0.0	0.0	23.9	17.0	13.6	0.0	43.2	0.0	2.3	0.0
RE 122	112.5	0.0	1.6	0.0	48.0	12.5	13.8	0.0	20.7	0.0	2.3	1.0
RE 124 + 150	115.5	0.0	0.0	0.0	39.6	12.8	12.5	0.0	31.9	0.0	3.2	0.0
RE 132	127.5	0.0	0.6	0.0	19.4	19.4	20.3	0.0	35.4	0.0	3.4	1.4
RE 133	129.0	0.0	0.0	0.3	17.4	10.4	7.6	0.0	59.0	0.0	5.0	0.3
RE 134 + 10	130.5	0.0	0.0	0.3	15.3	10.7	6.1	1.5	61.2	0.0	4.6	0.3
RE 143 + 140	144.0	0.0	0.0	1.9	66.3	10.7	17.9	0.0	3.1	0.0	0.0	0.0
RE 143+120	145.2	0.0	0.0	0.0	31.3	16.3	44.3	0.0	6.3	0.0	1.8	0.0
RE 148	151.5	0.0	0.0	0.0	14.3	9.4	10.7	0.0	64.6	0.0	1.0	0.0
RE 153	159.0	0.0	0.0	0.0	27.4	3.3	14.7	0.2	39.6	0.0	14.7	0.0
RE 154	160.5	0.0	0.0	0.0	2.6	69.5	13.2	0.0	11.6	0.0	3.2	0.0
RE 161 + 100	171.0	0.0	0.0	0.0	68.4	1.2	3.9	0.3	24.8	0.0	0.9	0.6
RE 170+40	184.9	Sterile										
RE 186	208.5	Sterile										

Table 6-2--continued.

Sample		Aquatic		Terrestrial							
number	meters	amorphous	dinocyst	resins	black debris	yellow brown	black brown	cuticles	plant tissue	woody	sporom.	fungi
RE 188	211.5	0.0	0.0	0.0	16.4	0.3	6.1	0.0	77.2	0.0	0.0	0.0
RE 190+10	214.6	0.0	0.0	0.6	7.2	31.9	53.9	0.0	3.6	0.0	2.8	0.0
RE 195	222.0	0.0	0.0	0.0	33.0	1.3	15.5	0.0	49.5	0.0	0.3	0.3
RE 220	259.5	Sterile										
RE 222+100	263.5	0.0	0.0	19.9	28.8	16.7	13.5	0.0	4.5	0.0	16.7	0.0
RE 241+40	291.4	0.0	0.0	0.5	25.5	2.2	18.6	0.0	48.2	0.0	4.9	0.0
RE 245	297.0	0.0	0.0	0.0	58.9	2.8	9.3	0.0	18.1	0.0	10.8	0.0
RE 251+30	306.3	0.0	0.0	3.5	29.9	4.9	34.8	0.0	16.2	0.0	10.7	0.0

Table 6-3. Palynodebris count data (in %) for the Uribe section. Meters from base of La Paz Formation. Organic matter categories are described in Table 1.

Sample		Aquatic	Terrestrial									
number	meters	amorphous	dinocyst	resins	black debris	yellow brown	black brown	cuticles	plant tissue	woody	sporom.	fungi
UR 376	-6	Barren										
UR 379	-4.5	Barren										
UR 380	-4	Barren										
UR 395+120	20.7	0.0	0.0	0.0	92.1	7.9	0.0	0.0	0.0	0.0	0.0	0.0
UR 409+70	41.2	0.0	0.3	0.3	52.9	27.8	12.5	0.0	3.4	0.0	1.2	1.5
UR 437+5	83	Barren										
UR 441	88.5	Barren										
UR 445	94.5	Barren										
UR 470	132	Barren										
UR 502	180	0.0	0.3	0.3	51.8	8.6	33.0	0.0	5.5	0.0	0.3	0.3
UR 506	186.0	0.0	0.0	0.9	52.8	10.3	10.3	0.0	24.9	0.0	0.9	0.0
UR 507	187.5	0.0	0.0	0.0	81.7	1.3	16.6	0.0	0.3	0.0	0.0	0.0
UR 527 + 100	218.5	0.0	0.0	3.2	94.2	2.6	0.0	0.0	0.0	0.0	0.0	0.0
UR 531+120	224.7	0.0	0.0	1.4	27.0	23.9	19.0	0.0	25.3	0.0	2.3	1.1
UR 542+40	240.4	Barren										
UR 545	244.5	Barren										
La Paz 361 m	361	0.0	0.0	0.3	58.2	5.5	20.3	0.0	14.8	0.0	0.6	0.3
La Paz 362m	362.0	0.0	0.0	0.3	49.9	11.3	9.3	0.0	28.7	0.0	0.6	0.0
UR 704+10	385.1	0.0	0.0	0.3	59.9	6.1	27.3	0.0	5.8	0.0	0.6	0.0
UR 726	418	0.0	0.0	0.6	52.9	3.4	11.5	0.0	28.4	0.3	2.6	0.3
UR 732	427.0	0.0	0.0	0.0	55.8	10.8	7.4	0.0	24.5	0.0	1.1	0.3
UR 761	470.5	0.0	0.0	0.3	71.7	9.2	6.6	0.0	9.2	0.0	2.6	0.3
UR 781+20	500.7	0.0	0.0	0.3	22.7	15.8	21.3	0.0	35.6	0.0	2.9	1.4
UR 812	547	0.0	0.0	0.0	34.8	5.2	21.2	0.0	34.8	0.0	1.5	2.4
UR 849	602.5	Barren										
UR 853	608.5	0.0	0.0	0.0	56.7	1.0	13.3	0.0	28.7	0.0	0.3	0.0
La Paz 632m	632.0	Barren										
La Paz 712 m	712	0.0	0.0	2.1	77.2	4.2	9.0	0.0	5.1	0.0	1.2	1.2

Table 6-3--continued.

Sample		Aquatic		Terrestrial								
number	meters	amorphous	dinocyst	resins	black debris	yellow brown	black brown	cuticles	plant tissue	woody	sporom.	fungi
La Paz 871m	871.0	0.0	0.0	3.5	75.1	2.3	17.3	0.0	1.7	0.0	0.0	0.0
La Paz 886 m	886	0.0	0.0	7.3	62.2	12.2	4.3	0.0	7.6	0.0	5.5	0.9
La Paz 989 m	989	Barren										
Esm 20m	1066	Barren										
Esm 21 m	1067	Barren										
Esm 24m	1070	Barren										

cluster groups in Figure 6-6). Similar lithofacies, therefore, could produce different palynofacies.

Increasing thermal alteration darkens particles (Traverse, 1988), however, the entire sections seem to be thermally immature according to the yellow color of trilete psilate spores (Thermal Alteration Index: 2 to 2-), therefore thermal alteration would not be a major factor when considering the organic matter distribution across the stratigraphic interval studied.

Discussion

Generally, the dispersed organic matter content of sediments from neritic, marginal marine, and lower coastal environments consists of two main components: organic matter derived from the continent (terrestrial in the classification, see Table 3-1), and organic matter produced in the ocean, such as dinoflagellate cysts and marine amorphous organic matter (Lorente, 1986; Traverse, 1988). Terrestrially-derived organic matter behaves like a clast in water, therefore, their abundance will decrease as the distance from the land increases. This is the basis for using palynofacies as indicators of variations in the distance to the shoreline, which ultimately can be related to changes in relative sea level. However, stochastic events such as retransporting of organic matter by oceanic currents and storms, palynomorphs transported by the wind, as well as changes in run-off and climate, can also have an influence on the organic matter content of sediments (Batten, 1996).

The sample groups of the Piñalerita cluster analysis (Fig. 6-4) could be ordered in an ideal gradient from fluvial/coastal to nearshore environments in the following manner. Barren samples could be associated with environments where seasonal subaerial exposure destroys all organic matter such as flood plains and sand bars (Lorente, 1986; Rull, 1997a). Groups 4, 1, 6, and 2 correspond to diverse subenvironments within fluvial system. Group 1 characterized by black debris that generally accumulate in

environments with well-oxygenated sediments where water table fluctuates periodically, such as in levee, point bar, proximal crevasse splay, and channel sand deposits (Boulter and Riddick, 1986; Pocock *et al.*, 1988; Van Vergen and Kerp, 1990; Tyson, 1995; Batten, 1996) . This type of organic matter, however, also could be found in levees and point bars in coastal plain systems (Lorente, 1986; Batten, 1996) or in barrier/beach and offshore sands (Bustin, 1988). Group 4 of samples (black debris and black brown) and Group 6 dominated by yellow brown organic matter accumulated in relatively aerobic environments where particulate organic matter was partially degraded. Dominance of this type of organic matter is frequent in channel-fill deposits and swampy areas (Batten, 1973; Lorente, 1986). Group 2 is characterized by yellow brown coupled with black brown, plant tissue and sporomorphs (the ecological significance of sporomorphs is analyzed in detail in next heading). This assemblage is generally found in lakes and oxbows generally in fluvial but also in coastal deposits where preservation of organic matter is enhanced by low oxygen, and permanent saturation of sediments (Lorente, 1986; Cohen *et al.*, 1989; Batten, 1996).

Group 3 probably accumulated in upper coastal plain deposits. Codominance of plant tissue and black brown, with occasional presence of marine dinoflagellate cysts is common in upper coastal plain deposits (Muller, 1959; Lorente, 1986). Plant tissue is usually abundant and well preserved in this type of environment especially when the coastal plain has mangroves associated (Bustin, 1988; Cohen *et al.*, 1989; Jaramillo and Bayona, 2000). Coastal plain is defined here as the coastal land under tidal influence.

Group 5 suggests lower coastal plain to innermost shelf conditions. High dominance of plant tissue with moderate abundances and diversity of marine dinoflagellate cysts is common in this type of sedimentary environments in tropical and subtropical regions (Lorente, 1986; Tyson, 1995; Jaramillo and Oboh, 1999). Plant tissue is usually abundant and well preserved in this type of environments where mangroves are productive and export large amounts of organic detritus to tidal creeks and nearshore

environments. This detritus is largely protected from oxidation thus suffering little chemical breakdown, specially in distributary banks and channels, inshore low-tide intertidal, and bay-bottom sandy muds as has been found in tropical Australia (Risks and Rhodes, 1985), the Niger delta (Bustin, 1988), the Orinoco delta (Muller, 1959; Scheihing and Pfefferkorn, 1984). Assemblages recovered in saltwater-influenced areas have a larger proportion (up to 10 times) the amount of structurally preserved matter than in freshwater as was found in Malaysia (Gastaldo and Staub, 1997).

A "paleobathymetric" curve for the Piñalerita section was constructed based on the stratigraphic arrangement of these groups (right side of Figure 6-1). This "paleobathymetric" curve shows the variation of the shoreline, and concomitant change of environments, in relation to a fixed point (the geographic location of the section).

In environments that are entirely continental, as in the Regadera and Uribe sections, organic matter must be analyzed in a slightly different manner. In continental systems the position and fluctuation of the water table exert a large influence in the preservation of the organic matter (Lorente, 1986). In general, the water table is progressive closer to the surface in environments closer to the coastal plain toward the ocean (Galloway and Hobday, 1996). Therefore, in a given fluvial profile, the dispersed organic matter would tend to be better preserved seaward. This is the basis for identifying variations in gross depositional environments using the organic matter groups produced by Euclidean analysis. Each subenvironment in fluvial environment possesses a characteristic type of organic matter that is mainly the product of the vegetation surrounding the place of accumulation, and the levels of energy, oxygenation, and saturation present during the accumulation of the organic matter (Lorente, 1986). However, the same depositional environment could also have different palynofacies due to differences in the geochemistry of the system (Gastaldo *et al.*, 1996); thus a channel deposit in the alluvial plain may have a different palynofacies than a similar channel in

the coastal plain as was showed by Gastaldo *et al.* (1996) for the Rajang river and delta in Malaysia.

The palynofacies groups identified in the analysis of the Regadera and Uribe sections (Fig. 6-6) were probably accumulated within fluvial environment. Organic matter offers no indications of marine influence in these sections. The interpretation of the environmental significance of each organic matter group is as follows. Groups A (yellow brown), C (black brown), and D (black debris with plant tissue) are typical of channel-fill deposits or swampy areas (see discussion for Groups 4 and 6 above). However, various states of saturation and oxidation within these subenvironments can modify the degree of alteration of the organic matter (Tyson, 1995). Group B (plant tissue, with sporomorphs and black debris) probably accumulated in lakes or oxbows lakes (see discussion above for Group 2). Group E (black debris) probably accumulated in levees, sand bars, or proximal crevasse splay deposits (see discussion above for Group 1).

In general terms, group E and sterile samples would tend to be abundant in more upper fluvial environments, where the water table is deeper, and oxidation of organic matter is stronger (Galloway and Hobday, 1996). Groups A, C, and D would tend to be more abundant in intermediate areas of fluvial environment where organic matter, although partially degraded, is still preserved. Finally, group B would be in lower fluvial to coastal plain environments where organic matter tends to be better preserved. "Paleobathymetric" curves for the Uribe and Regadera sections were constructed based on the stratigraphic arrangement of these groups (right side of Figures 6-2, 6-3). This "paleobathyemtric" curve shows the variation of base level, and concomitant change of environments, in relation to a fixed point (the geographic location of the section).

Paleoecology

Previous Studies

The pollen/spores record appears to provide an excellent measure of local to subregional vegetation (Traverse, 1986). Pollen transport, especially in dense tropical rainforests, is limited, and can be expected to be confined mostly to the plant community of origin (Kam-biu and Colinvaux, 1988; Wing and DiMichele, 1992). Most of the extraneous elements are introduced by water rather than wind, especially in active channel deposits, or oxbow lakes that are periodically flooded. Major biases result from different rates in pollen production (Wing and DiMichele, 1992) that can over or under-represent a taxon in an assemblage. In lowland tropical rainforests, however, studies have shown that there is a good agreement between the pollen/spores assemblages found in the sediment and the vegetation communities near the site of deposition, and that the few wind-pollinated taxa in rainforests do not dominate pollen assemblages (Kam-biu and Colinvaux, 1988).

The ecological significance of extinct palynomorph assemblages can be inferred in two basic ways: by analogy of its members with living relatives, or from the spatial distribution of fossils, taphonomy and sedimentary environments. The first method is not very reliable in pre-Neogene sediments (Traverse, 1988) because it is very difficult to assess the natural relationship of fossil taxa, and even if pollen grains are identical, it does not necessarily mean that they were produced by the same plant, or that the taxon was living in similar paleoecological conditions as today. However, in some cases (e.g., *Nypa* pollen and its fossil pollen counterpart *Spinizonocolpites*) the ecological significance of a taxon has been securely assessed (Germeraad *et al.*, 1968). The second method is the use of multivariate statistics. The use of multivariate statistical techniques relies on the assumption that co-occurring palynomorphs lived in similar environments and/or were subject to the same depositional processes. Statistical parameters, then, help to evaluate the strength of a given co-occurrence. This approach allows us to test previous

hypotheses on specific palynomorph paleoenvironments. Also it can provide new hypothesis of palynomorph-environment relationships that can be tested in future studies.

Most paleoecological studies of Paleogene pollen/spores taxa in the tropics have used the first approach, i.e., analogy with modern relatives. Only three papers have used some type of statistical analysis of the sporomorph distribution (Hoorn, 1994; Rull, 1997a, b). The paleoecological significance of the taxa found in this study are shown in Table 6-4 and are based upon an extensive literature review.

Results

A non-metric multidimensional scaling (MDS) was performed on a subset of data from the original distribution range charts (Table 6-5). Thirty-eight palynomorphs were selected for the analysis. They were selected based upon abundance (total abundances greater than 50 grains, when sum of all samples was considered), and pollen/spores with recognized paleoenvironmental significance. Samples with less than 50 grains were eliminated from this analysis because they probably do not represent a reliable representation of the palynoflora and only would introduce noise to the analysis.
The non-metric multidimensional scaling (MDS) analysis produced the following groups (Fig. 6-8):

Group A: *Retimonocolpites regio, Bombacacidites annae, Psilamonocolpites grandis*

Group B: *Proxapertites humbertoides, Retidiporites magdalenensis, Proxapertites cursus, P. operculatus*

Group C: *Mauritiidites franciscoi*

Group D: *Longapertites* spp.

Group E: Dinoflagellate cysts

Group F: *Spinizonocolpites* "grandis", *Retitricolpites magnus, Retistephanoporites* "minutipori", *Psilaperiporites* "pauciporatus", *Retitricolporites guianensis, Echitriporites trianguliformis, Psilatricolporites crassus, Polypodiisporites specious, Laevigatosporites*

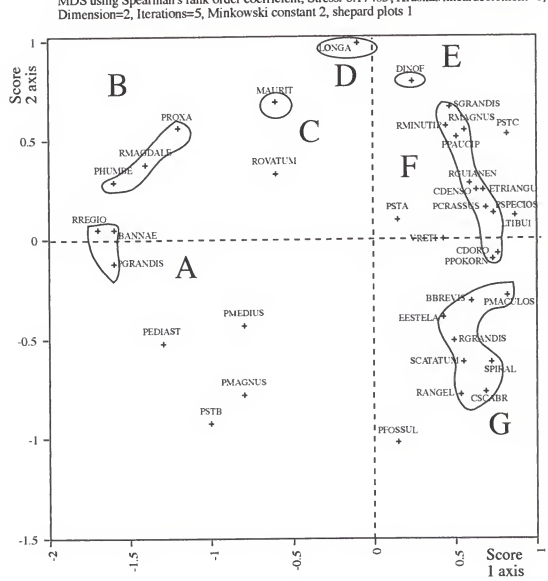


Figure 6-8. Scattergram of species ordinations, from a non-metric multidimensional scaling (MDS) analysis using Spearman's rank-order coefficient. See discussion about the 7 groups identified. Species asignations are as follows: "Psilatriletes" sp. A=PSTA, "Psilatriletes" sp. B=PSTB, "Psilatriletes" sp. C=PSTC, *Bombacacidites annae*=BANNAE, *Bombacacidites brevis*=BBREVIS, *Cicatricosisporites dorogensis*=CDORO, *Clavatricolpites* "densoclavatus"=CDENSO, *Cyclusphaera* "scabratus"=CSCABR, *Echiperiporites estelae*=EESTELA, *Echitriporites triangliformis* var. "orbicularis"= ETRIANGU, *Laevigatosporites tibui*=LTIBUI, *Pediastrum*=PEDIAST, *Perisyncolporites pokornyi*=PPOKORN, *Polypodiaceoisporites*? "fossulatus"=PFOSSUL, *Polypodiisporites speciosus*=PSPECIOS, *Psilamonocolpites grandis*=PGRANDIS, *Psilamonocolpites medius*=PMEDIUS, *Psilaperiporites* "*pauciporatus*"=PPAUCIP, *Psilatricolporites crassus*=PCRASSUS, *Psilatricolporites maculosus*=PMACULOS, *Retibrevitricolporites* "grandis"=RGRANDIS, *Retidiporites magdalenensis*=RMAGDALE, *Retimonocolpites* "ovatum"=ROVATUM, *Retimonocolpites regio*=RREGIO, *Retistephanoporites* "minutipori"=RMINUTIP, *Retistephanoporites angelicus*=RANGEL, *Retitricolpites magnus*=RMAGNUS, *Retitricolporites guianensis*=RGUIANEN, *Spiniozonocolpites* "grandis"=SGRANDIS, *Spirosyncolpites spiralis*=SPIRAL, *Striatricolpites catatumbus*= SCATATUM, *Verrutricolporites* "reticulatus"=VRETI, *Mauritiidites* spp.=MAURIT, *Proxapertites humbertoides* and *P. cursus*=PROXA, *Longapertites* spp.=LONGA, Dinoflagellate cysts=DINOF, *Proxapertites magnus*=PMAGNUS, *Proxapertites humbertoides*=PHUMBE

Table 6-4. Previous paleoecological interpretations for sporomorphs found in this study

Taxa	paleoecology	author	statistical analysis
Spinizonocolpites baculatus	mangrove	Jan du Chene, 1980	none
Proxapertites operculatus	mangrove	Van der Kaars, 1983	none
Mauritia	swamps forming almost pure stands	Colinvaux, 1987	none
Magnastriatites howardii	fresh-water, floating aquatic fern	Graham, 1993	none
Echiperiporites estelae	coastal brackish-water	Graham, 1993	none
Psilatricolporites crassus	mangrove	Graham, 1993	none
Zonocostites ramonae	mangrove	Graham, 1993	none
Brevitricolpites variabilis	mangrove	Graham, 1993	none
Mauritiidites franciscoi group	permanently flooded fluvial/coastal plain	Rull, 1998	none
Proxapertites operculatus and P. cursus	mangrove	Muller, 1979	none
Spinizonocolpites baculatus, echinatus	mangrove	Muller, 1979	none
Brevitricolpites variabilis, Retibrevitricolpites triangulatus, R. catatumbus, R. increatus (the *Brevitricolpites* group)	mangrove	Gonzalez, 1967	none
Bombacacidites soleaformis	coastal environments?	Colmenares and Teran, 1993	none
Psilatricolporites operculatus	coastal environments?	Colmenares and Teran, 1993	none
Verrucatosporites usmensis, Laevigatosporites vulgaris	swampy freshwater/brackish water	Rull, 1997a	PCA
Mauritiidites franciscoi Group	morichales	Rull, 1997a	PCA
Bombacacidites baumflaki, Perisyncolporites pokornyi, Retritricolporites guianensis, R. irregularis, D. adriennis	lowland forest (coastal forest swamps)	Rull, 1997a	PCA
Mauritiidites franciscoi, Pediastrum, Botryococcus Group	fresh water swamps/lakes	Rull, 1997b	PCA
Psilamonocolpites medius, Deltoidospora adriennis Group	brackish water	Rull, 1997b	PCA
Monoporites annulatus, Crototricolpites annemariae, Echitricolporites spinosus, Fenestrites longispinosus, Azolla	fresh water lakes/ponds	Lorente, 1986	none
Monoporites annulatus, Echiperiporites estelae	fresh water lakes/ponds	Lorente, 1986	none
Monoporites annulatus, Psilaperiporites minimus	fresh water lakes/ponds	Lorente, 1986	none
Mauritiidites franciscoi, Retitricolporites irregularis	alluvial plain/ upper delta?	Lorente, 1986	none
Mauritiidites franciscoi, Jandufouria seamrogiformis	alluvial plain/ upper delta?	Lorente, 1986	none
Mauritiidites franciscoi	alluvial plain/ upper delta?	Lorente, 1986	none
Monoporites annulatus, Grimsdalea magnaclavata	coastal plain swamps/lower delta swampy	Lorente, 1986	none
Mauritiidites franciscoi	coastal plain swamps/lower delta swampy	Lorente, 1986	none
Echiperiporites estelae, Laevigatosporites vulgaris, Laevigatosporites usmensis	coastal plain swamps/lower delta swampy	Lorente, 1986	none
Mauriidites franciscoi, Scabratricolporites planetensis	coastal plain /lower delta?	Lorente, 1986	none

Table 6-4--continued.

Taxa	paleoecology	author	statistical analysis
Psilamonocolpites medius			
Zonocostites ramonae, Psilatricolporites crassus	coastal plain /lower delta?	Lorente, 1986	none
Zonocostites ramonae, Perisyncolporites pokornyi	coastal plain /lower delta?	Lorente, 1986	none
Zonocostites ramonae, Mauritiidites franciscoi	lower coastal plain to fluviomarine	Lorente, 1986	none
Zonocostites ramonae , highly diversified (30 to 60 species) microplankton, microforams	shallow marine	Lorente, 1986	none
Aglaoreidia	aquatic herb	Frederiksen, 1985	none
Bombacacidites annae	damp tropical forests	Graham and Jarzen, 1969	none
Monoporites annulatus	open water habitats, mud and sand flats.	Hoorn, 1993	none
Retitricolporites irregularis. Striatricolpites catatumbus, Bombacacidites baculatus	alluvial plain	Hoorn, 1993	none
Magnastriatites howardi	freshwater fern	Germeraad *et al* ., 1968	none
Verrucatosporites usmensis	climbing fern?	Germeraad *et al* ., 1968	none
Spinizonocolpites echinatus	mangrove	Germeraad *et al* ., 1968	none
Spinizonocolpites baculatus	mangrove	Germeraad *et al* ., 1968	none
Proxapertites operculatus	mangrove?	Muller, 1968	none
Echitriporites trianguliformis	coastal plant	Germeraad *et al* ., 1968	none
Psilatricolporites crassus	mangrove?	Germeraad *et al* ., 1968	none
Zonocostites ramonae	mangrove	Germeraad *et al* ., 1968	none
Spinizonocolpites prominatus	mangrove	Westgate and Gee, 1990	none
Lygodiumsporites adriennis	back-mangrove swamp ferns	Westgate and Gee, 1990	none
Retitricolporites guianensis, Psilatricolporites operculatus, Echitricolporites maristellae, Magnastriatites grandiosus, Perisyncolporites pokornyi, Crototricolpites annemariae, Crassiectoapertites colombianus, Echiperiporites akanthos, Azolla sp.	flooded pool in overbank environment	Hoorn, 1994	TWINSPAN
Mauritiidites franciscoi, Heterocolpites incomptus, Retitricolporites irregularis.	abandoned channel	Hoorn, 1994	TWINSPAN
Dinocyst, microforams, *Perisyncolporites pokornyi, Retitricolporites irregularis.* Moderate abundances of *Z. ramonae.*	brackish	Hoorn, 1994	TWINSPAN
Echitriporites trianguliformis	coastal plain	Colmenares and Teran, 1993	none

Table 6-5. Abundance of selected taxa used in paleoecological analysis. Samples with < 50 grains were eliminated
P=Piñalerita section, R=Regadera section, U=Uribe section

Section	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
taxa sample (meters)	5.4	31	37	47	79	81	105	155	196	214	266	311	475	637	661	689	697	703	711	716	725
"Psilatriletes" sp. A	2	12	10	12	3	7	29	22	24	5	36	16	3	13	17	1	31	46	35	25	43
"Psilatriletes" sp. B	0	3	2	0	16	5	59	5	37	29	33	22	0	15	8	1	3	3	2	2	1
"Psilatriletes" sp. C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	1	21	9	10	3	3
Bombacacidites annae	0	34	70	4	18	5	9	0	29	60	6	3	0	0	0	0	0	0	0	0	0
Bombacacidites brevis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	1	0
Cicatricosisporites dorogensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	1	4	7	6	5	15
Clavatricolpites "densoclavatus"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	2	15	9	8	13	2
Cyclusphaera "scabratus"	0	0	0	0	0	0	0	0	0	0	0	0	0	6	1	1	0	1	0	0	0
Echiperiporites estelae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1
E. trianguliformis var. "orbicularis"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	2	4	8	3	7	2
Laevigatosporites tibui	0	0	1	0	2	0	1	0	25	9	13	3	0	8	22	4	48	126	169	186	39
Pediastrum	1	21	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Perisyncolporites pokornyi	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	4	3	1	1	4	3
Polypodiaceoisporites? "fossulatus"	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	1	0	0	0	1	0
Polypodiisporites specious	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2	33	32	35	13	22
Psilamonocolpites grandis	57	4	3	2	0	6	1	0	0	2	0	1	0	0	0	0	0	0	0	0	0
Psilamonocolpites medius	8	4	15	5	4	2	8	1	2	6	3	2	0	4	3	1	6	0	1	0	0
Psilaperiporites "pauciporatus"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	3	10	9	1	6	.2
Psilatricolporites crassus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	31	11	36	34	2	13	7
Psilatricolporites maculosus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	2	3
Retibrevitricolporites "grandis"	0	0	0	0	0	0	0	0	0	0	0	0	0	9	2	2	5	0	0	1	0
Retidiporites magdalenensis	33	0	0	2	38	2	5	0	0	0	2	0	0	0	0	0	0	0	0	0	0
Retimonocolpites "ovatum"	0	0	0	0	20	0	9	3	180	33	25	14	1	1	4	4	9	8	3	6	2
Retimonocolpites regio	3	9	18	16	5	5	6	3	3	0	0	0	1	0	0	0	0	0	0	0	0
Retistephanoporites "minutipori"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	3	11	3
Retistephanoporites angelicus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Retitricolpites magnus	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	6	28	15	4	9	4
Retitricolporites guianensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	3	19	17	9	4	17
Spinizonocolpites "grandis"	0	0	0	0	0	0	0	0	0	0	0	0	0	0	20	5	7	9	2	6	6
Spirosyncolpites spiralis	0	0	0	0	0	0	0	0	0	0	0	0	0	15	3	1	3	1	1	1	0

Table 6-5--continued.

Section	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P	P
taxa sample (meters)	5.4	31	37	47	79	81	105	155	196	214	266	311	475	637	661	689	697	703	711	716	725
Striatricolpites catatumbus	0	0	0	0	0	0	0	0	0	0	0	0	0	2	2	1	0	0	0	1	0
Verrutricolporites "reticulatus"	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	2	2	3	0	0	0
Mauritiidites spp.	11	9	6	4	43	17	36	17	10	18	19	2	1	6	10	1	37	20	38	33	8
Proxapertites cursus+operculatus	1	3	2	3	158	5	314	29	10	32	25	4	0	2	2	2	1	2	1	4	1
Longapertites spp.	0	0	0	0	0	0	1	2	0	1	1	1	394	2	0	0	1	1	1	7	2
Dinoflagellates	3	1	4	1	0	0	0	0	0	0	0	2	0	0	125	4	4	11	1	17	51
Proxapertites magnus	0	13	1	0	0	0	0	1	2	10	0	0	0	2	1	0	0	0	0	0	0
Proxapertites humbertoides	2	0	16	6	12	16	5	6	18	57	4	2	0	0	0	1	0	0	1	0	0

Section	P	P	P	P	P	P	P	R	R	R	R	U	U	U	U	U
taxa sample (meters)	734	738	753	759	767	776	785	31.2	145	291	306	225	471	547	712	886
"Psilatriletes" sp. A	65	17	26	24	27	38	24	45	2	13	53	11	21	4	24	47
"Psilatriletes" sp. B	3	5	4	2	3	7	1	17	2	0	5	11	25	3	20	13
"Psilatriletes" sp. C	3	1	1	0	2	0	1	49	3	0	10	0	0	2	9	1
Bombacacidites annae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Bombacacidites brevis	2	1	9	7	7	4	19	0	0	0	0	0	0	0	0	0
Cicatricosisporites dorogensis	4	22	26	64	15	89	14	0	0	33	90	0	0	0	0	0
Clavatricolpites "densoclavatus"	6	4	0	4	2	1	4	7	0	3	1	0	0	0	0	0
Cycluzphaera "scabratus"	1	6	1	6	2	2	15	1	0	1	2	1	0	1	3	4
Echiperiporites estelae	1	2	0	3	5	10	0	0	0	0	1	0	0	0	0	0
E. trianguliformis var. "orbicularis"	12	4	4	2	3	0	1	0	0	13	0	0	0	0	0	0
Laevigatosporites tibui	65	39	72	52	27	41	57	3	131	19	25	1	2	51	13	14
Pediastrum	0	0	0	0	0	0	0	3	0	0	0	2	0	0	0	0
Perisyncolporites pokornyi	10	13	9	14	11	49	7	0	0	6	7	0	0	0	0	0
Polypodiaceoisporites? "fossulatus"	2	2	6	0	0	3	0	0	0	0	0	0	0	3	11	16
Polypodiisporites specious	31	21	86	12	12	15	14	0	0	7	16	0	2	5	0	0
Psilamonocolpites grandis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Psilamonocolpites medius	5	4	8	6	3	4	3	14	1	3	1	0	3	0	0	0
Psilaperiporites "pauciporatus"	1	0	1	0	2	0	0	0	0	0	0	0	0	0	0	0
Psilatricolporites crassus	63	4	1	3	1	6	17	0	0	2	85	0	0	0	0	0
Psilatricolporites maculosus	4	2	5	3	3	5	4	0	0	5	12	0	0	0	2	0
Retibrevitricolporites "grandis"	2	3	1	4	30	12	38	10	0	0	0	1	0	2	0	0

Table 6-5--continued.

Section	P	P	P	P	P	P	R	R	R	R	U	U	U	U	U
taxa sample (meters)	734	738	753	759	767	776	785	31.2	145	291	306	225	471	547	712	886
Retidiporites magdalenensis	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Retimonocolpites "ovatum"	7	7	5	5	2	8	12	7	3	0	0	9	17	7	1	0
Retimonocolpites regio	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Retistephanoporites "minutipori"	16	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Retistephanoporites angelicus	0	1	19	12	7	12	4	0	0	6	15	0	0	0	0	0
Retitricolpites magnus	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Retitricolporites guianensis	12	10	0	1	5	8	1	0	0	0	0	0	0	0	0	0
Spinizonocolpites "grandis"	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Spirosyncolpites spiralis	0	9	0	5	8	5	25	11	0	1	0	1	1	3	10	0
Striatricolpites catatumbus	1	6	3	3	2	3	9	0	0	0	0	0	1	1	0	1
Verrutricolporites "reticulatus"	7	36	0	1	0	0	4	0	0	1	0	0	0	0	0	0
Mauritiidites spp.	7	16	4	5	9	9	8	6	7	10	15	7	4	9	0	0
Proxapertites cursus+operculatus	4	0	0	0	0	1	3	0	0	1	0	1	1	5	0	0
Longapertites spp.	3	3	1	0	0	1	1	170	1	0	1	1	6	2	0	0
Dinoflagellates	13	5	0	0	0	0	0	2	0	1	4	4	2	0	0	0
Proxapertites magnus	0	2	0	0	1	0	0	1	0	0	0	0	0	0	0	0
Proxapertites humbertoides	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0

tibui, *Clavatricolpites* "densoclavatus", *Cicatricosisporites dorogensis*, *Perisyncolporites pokornyi*, "Psilatriletes" sp. C

Group G: *Bombacacidites brevis*, *Psilatricolporites maculosus*, *Echiperiporites estelae*, *Retibrevitricolporites* "grandis", *Striatricolpites catatumbus*, *Spirosyncolpites spiralis*, *Retistephanoporites angelicus*, *Cyclusphaera* "scabratus".

Discussion

Fossil pollen assemblages can be used to identify diverse sedimentary environments, as has been shown for fluvial strata of the Bighorn Basin (Farley, 1990) and recent delta systems as in the Orinoco delta (Muller, 1959), and the Mississippi delta (Chmura, 1994). These assemblages generally differ in abundance of taxa rather than presence-absence (Farley, 1990).

The interpretation of the MDS analysis was done based upon the spatial position of taxa along the first and second order axes, and on literature review (see Table 6-4). The axes indicate the coordinates of the n species in t dimensions that are calculated from a similarity matrix (Manly, 1994). The main goal was to identify fluvial plain-nearshore trends, if present. The environmental interpretations (fluvial, coastal) are used in a relative sense rather than in an absolute one. These terms only represent the position of a palynomorph assemblage relative to each other rather than an absolute position along the fluvial-nearshore gradient. Variations in the relative proportions of those groups through time are interpreted here to represent variations in major depositional systems that can be linked in a sequence stratigraphic context.

The groups given by the MDS analysis can be divided in two large groups that are clearly separated along the axis 1: Groups A and B, and Groups E, F, and G (Fig. 6-8). Groups C and D are in intermediate value. These two large groups are separated due to different ages. Taxa present in A and B are typical elements of Paleocene floras such as *Proxapertites*, *Bombacacidites annae*, and *Retidiporites magdalenensis* (Germeraad *et*

al., 1968). Taxa of groups E, F, and G are typical of Eocene deposits (e.g., *Psilatricolporites crassus*, *Retitricolporites magnus*, *Perisyncolporites pokornyi*). Taxa of groups C and D are common in both Paleocene and Eocene deposits (Muller *et al.*, 1987).

The grouping along the axis 2 seems to be due to a gradient fluvial to coastal environments that could be organized in the following manner. Group A seems to indicate Paleocene fluvial plain environments. Pollen of *Bombacacidites annae* is very similar to extant *Bombax* (Germeraad *et al.*, 1968), a typical element of damp tropical forests (Graham and Jarzen, 1969). Group B indicates Paleocene coastal environments. *Proxapertites cursus* and *P. operculatus* have a morphology similar to *Nypa* pollen and are concentrated in Paleogene deltaic and shallow marine sediments (Muller, 1979).

Group C indicates pure stands of *Mauritiidites*. This pollen is very similar to extant *Mauritia* pollen, a palm that generally forms pure or mixed stands in permanently flooded and poorly drained soils in depressions in the flood or coastal plain (Muller, 1979; Lorente, 1986; Colinvaux, 1987; Hoorn, 1994; Rull, 1997a, b; 1998). This interpretation is also confirmed by the isolation of *Mauritiidites* in the ordination as also was found by the PCA analysis of Rull (1997a). *Mauritia* pollen has low dispersal capabilities and its presence in sediment is almost restricted where palm is growing (Rull, 1998). This has been shown in sediments from both coastal swamps (Muller, 1959), and inland fluvial valleys (Rull, 1998). It is rarely present in marine sediments (Muller 1959). The presence of *Mauritiidites* pollen indicates presence of *Mauritia* communities near the site of deposition (Rull, 1998).

Group D is composed of a single taxon: *Longapertites* spp. (mainly *L. proxapertitoides*). *Longapertites* probably was produced by some type of palm (Muller, 1979) but its autoecology is uncertain. It could be suggested that it is produced by a palm that formed pure stands similar to *Mauritiidites* because it is also isolated in the ordination analysis (Fig. 6-8). Therefore, this group would represent stressful conditions

in the floodplain or coastal plain perhaps in permanently or semipermanently flooded areas.

Group G probably indicates Eocene fluvial deposits. *Bombacacidites* is a member of "Bombacaceae" (Germeraad *et al.*, 1968, Muller *et al.*, 1987), a small nonmonophyletic group of tropical trees that live in dense rain forest in South America and open savannas and weedy habitats in Africa (Heywood, 1985). "Bombacaceae" is nested within Malvacea, a monophyletic family (APG, 1988; Judd *et al.*, 1999) *Striatricolpites catatumbus*, very similar to pollen of extant Leguminosae *Crudia*, was suggested as a fluvial plain element by Hoorn (1993). *Crudia* is a typical riverine forest element (Hoorn, 1993). Lorente (1986) associated *Echiperiporites estelae* to fresh water lakes and ponds in alluvial plain environments based on lithofacies and organic matter analysis. Graham (1993) associates it with coastal brackish-water associated with *Rhizophora* mangrove. This taxa, however, was not associated with any mangrove element in MDS analysis.

Group F indicates Eocene coastal plain conditions. *Spinizonocolpites* is very similar to pollen of extant *Nypa*, a mangrove palm of southeast Asia, and has been found in coastal plain sediments in the Paleogene of Africa, South America, Europe, India, Borneo, and southeast United States (Germeraad *et al.*, 1968; Muller, 1979; Jan du Chêne, 1980; Westgate and Gee, 1990). This group also contains *Psilatricolporites crassus,* pollen very similar to extant *Pelliciera rhizophorae* that is a mangrove element distributed in the Pacific coast from Costa Rica to northern Ecuador. *Psilatricolporites crassus* has been found associated with coastal plain environments in South America and the Caribbean (Germeraad *et al.*, 1968; Graham, 1977; Lorente, 1986; 1993). *Echitriporites trianguliformis* was tentatively suggested as part of coastal communities by Germeraad *et al.* (1968) and Colmenares and Terán (1993) for Paleogene deposits of Southwestern Venezuela. This suggestion is here supported by its close association in the ordination analysis with *Spinizonocolpites* and *Psilatricolporites crassus*. Rull (1997a) in

his PCA analysis found *Retritricolporites guianensis* and *Perisyncolporites pokornyi* grouping together and interpreted the assemblage as indicative of coastal forest swamps. Here, these two taxa are grouping together again, and associated to *P. crassus* and *Spinizonocolpites* suggesting a coastal environment. However, *Retritricolporites guianensis* and *Perisyncolporites pokornyi* were also suggested as part of the riparian vegetation in Colombian Amazon during the Miocene (Hoorn, 1994). The same author states that abundant *Perisyncolporites pokornyi* was also found co-occurring with dinoflagellate cysts and *Zonocostites ramonae* (pollen of the extant mangrove, *Rhizophora*). This concurrence of *P. pokornyi* and *Z. ramonae* also was found by Lorente (1986) in Neogene deposits of Eastern Venezuela. Modern relatives of *Polypodiisporites* are spores of *Polypodium* (Polypodiaceae), that are widespread in the tropics. Some *Polypodium* species usually dominate fern fresh-water or slightly brackish swamps between the mangrove belt and *Mauritia*-dominated vegetation in the modern Orinoco delta (Rull 1997a). The ecological status of *Cicatricosisporites dorogensis* is uncertain. Modern relatives (*Schizeae* and *Mohria*) mostly inhabit dry, open, or semiopen habitats (*Schizeae*) or open forests, sandy soils or decaying logs (*Mohria*) (Germeraad *et al.*, 1968; Kramer, 1990; Moran, 1998). Here, however, it is closely associated to *Perisyncolporites pokornyi*, suggesting a habitat related to coastal riverine conditions.

Group E indicates nearmost neritic conditions. Most of fossil dinoflagellate cysts are from neritic origin (Evitt, 1985). *Homotryblium* and *Polysphaeridium* have been reported as a marginal marine taxon by Köthe (1990), Zevenboom *et al.* (Zevenboom *et al.*, 1994), Brinkhuis (1994), Dale (1996), and Jaramillo and Oboh (1999).

Several samples yielded very few or no palynomorphs. These types of samples could indicate normal oxidized floodplain conditions that are characterized by variegated mudstone and usually yield poor recovery of palynomorphs (Farley, 1990).

The curves plotted in Figures 6-8, 6-9, 6-10, and 6-11 are the abundances of the each of the 7 groups (A-E) defined by the MDS analysis. The abundances for each of the curves were normalized to 300 grains for the samples that had counts greater than 300 grains. An additional curve consists of the abundance of reworked dinocysts. Higher abundances of reworked material may be expected during highstand and lowstand systems tracts because clast input from the continent is higher. The status of "reworked" for a dinocyst or pollen was establish on the following basis; (a) if it has not been reported for the Paleocene or Eocene (e.g., *Dinogymnium*, *Odontochitina*), and (b) if it has a Paleogene record but it became extinct before the latest Paleocene in northern South America (e.g., *Buttinia andreevi*).

The last curve represents a relative paleoenvironmental curve. It is a weighted mean ($\sum n_i$ (i)/n) of the fluvial, coastal, and nearshore groups identified in the MDS analysis, where n represents the total number of taxa (abundance) in a particular sample and n_i represents the abundance of each ecological group; (i) represents weighted categories whereby fluvial (groups A, G), coastal (groups B, F), and innermost neritic groups (group E) are weighted 1, 2 and 3 respectively. A particular sample can contain a palynomorph assemblage composed of pollen/spores that lived in the coastal plain, plus a set of sporomorphs transported from fluvial areas by rivers. The value produced by the weighted mean is called the palynomorph paleoenvironmental index (PPI) which combines all the information given by the palynomorphs of a sample into a meaningful value, that represents the average given by the whole assemblage. Plotting this value through the section can provide us with general trends in depositional environment changes (Figs. 6-9 to 6-11). The PPI curve for the Eocene interval (PPIe) was calculate using groups E (inner neritic), F (coastal), and G (fluvial), while PPI curve for the Paleocene (PPIp) was done using groups A (fluvial) and B (coastal). Samples that had less than 10 grains after including all groups were not used to calculate the PPI.

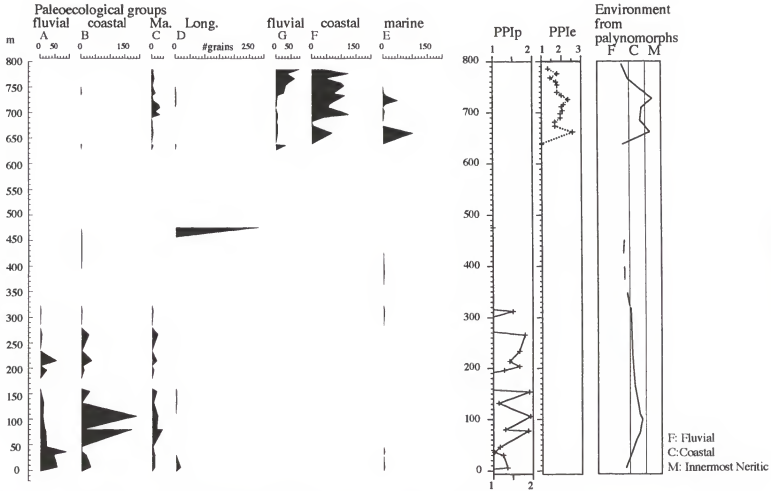


Figure 6-9. Paleoenvironmental interpretation of Piñalerita section based in abundance of 7 paleoecological groups derived from the MDS analysis (see text for discussion). PPIp=Palynomorph Paleoenvironmental Index for the Paleocene; PPIe. Palynomorph Paleoenvironmental Index for the Eocene (refer to Figure 6-8 for groups used in calculation of PPI' indexes). Ma=*Mauritiidites*, Long.=*Longapertites* group

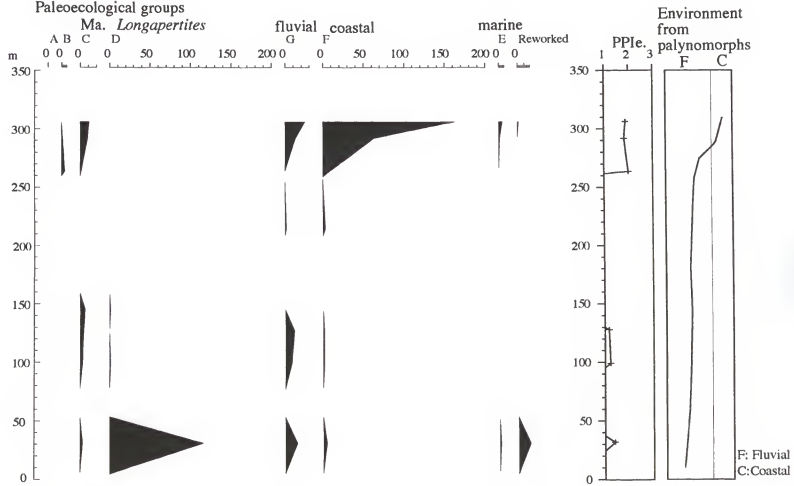


Figure 6-10. Paleoenvironmental interpretation of Regadera section based in abundance of 7 paleoecological groups derived from the MDS analysis (see text for discussion). PPIe. Palynomorph Paleoenvironmental Index for the Eocene (refer to Figure 6-8 for groups used in calculation of PPI indexes). Ma.=*Mauritiidites* group.

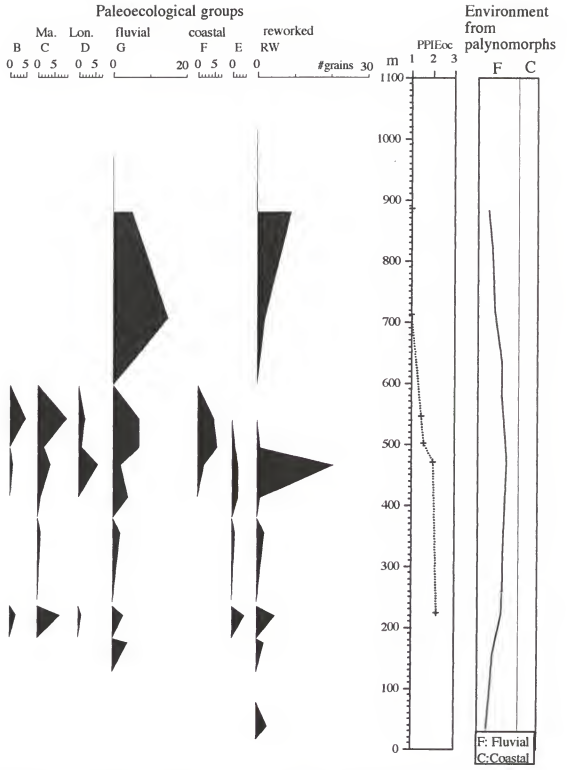


Figure 6-11. Paleoenvironmental interpretation of Uribe section based in abundance of 7 paleoecological groups derived from the MDS analysis (see text for discussion). PPIe:Palynomorph Paleoenvironmental Index for the Eocene (refer to Figure 6-8 for groups used in calculation of PPI indexes). Ma:*Mauritiidites*, Long:*Longapertites*

Lithology

Previous Studies

Each of the sections is located in a different area, Piñalerita in the Llanos foothills, Uribe in the Middle Magdalena Valley, and Regadera in the Catatumbo Basin (Figs. 3-1, 4-1). The stratigraphic nomenclature for each section is described here. In the Catatumbo area three formations comprises the Paleocene-Eocene: Cuervos, Mirador, and Carbonera Formations. The Cuervos Formation was named by Notestein *et al.* (1944) from Quebrada Los Cuervos in the Catatumbo area, 200km north of the Regadera section. The formation is composed mainly of claystones and shales, with abundant coal beds in its lower part and some evidence of marine influence; the upper part consists of gray and greenish-gray claystones with locally abundant red, yellow, and purple mottling (Notestein *et al.*, 1944). Thickness range from 282 to 490 meters increasing northward. The contact with overlying Mirador Formation is sharp, and locally unconformable (Notestein *et al.*, 1944). In the area of La Victoria creek, Germeraad *et al.* (1968) dated it as Paleocene (pollen zone of *Retidiporites magdalenensis*). In the Tibú anticline, Gonzalez (1967) dated the upper Cuervos as upper Paleocene-lower Eocene based on pollen. Sutton (1946) reports a mollusc brackish to marine fauna of *Ostrea* sp., *Anomia*? sp., and *Diplodonta*? from a black shale close to the base of the formation in Puerto Salado area.

The Mirador Formation was named by F. de Loys in a 1918 private report (Porta, 1974), and then was redefined by Notestein *et al.* (1944). Type locality is from Cerro Mirador, upper Lora river, District of Colón (Venezuela), in the Maracaibo Basin, approximately 230km north of the Regadera section. It is divided into three units: a lower unit, 110-355m thick, predominantly composed of clean, massive, fine to coarse-grained sandstones and in part conglomerates. A middle shaly unit, 10-70m thick, and an upper unit, 40-75m thick, composed of sandstone, thinly bedded and less clean than the lower unit. The overall thickness of the formation ranges from 160 to 400m, thickening

westward and northward (Notestein *et al.*, 1944). The lower contact with Cuervos Formation is sharp, easily recognized, and locally an angular unconformity can be seen (Quebrada Aguacaliente and Gonzalez anticline) (Notestein *et al.*, 1944). The time involved with this unconformity is uncertain. The top of the Mirador is where clean sandstones are overlaid by gray micaceous sandy shales of the Carbonera Formation. It is transitional in some areas (Rio de Oro) and reported as unconformable in some others in Venezuela (Notestein *et al.*, 1944). In the area of La Victoria (Venezuela), Germeraad *et al.* (1968) dated a correlative unit as lower to middle Eocene (pollen zones of *R. triangulatus*, *P. crassus*, and *R. guianensis*). In the Tibú anticline, Gonzalez (1967) dated it as lower to middle Eocene based on pollen. Germeraad *et al.* (1968) stated that Gonzalez flora is "anomalous" because it contained *Cicatricosisporites dorogensis* rather low in the Mirador (pollen zone of *Verrucatosporites usmensis*), suggesting an upper Eocene age. Colmenares and Terán (1993) dated the formation as early to early middle Eocene using palynological data.

The Carbonera Formation was named by Notestein *et al.* (1944) from Quebrada Carbonera in the Catatumbo area, 80km north of the Regadera section. It consists of a thick series of gray claystones, red and yellow mottled, with some gray arcillaceous sandstone intercalations, 5 to 30 meters thick. Coals are present in lower and upper parts of the formation. Glauconite and a mollusk fauna indicating brackish to marine conditions were found 100 meters below the top and 60 meters above the base of the formation. Thickness range from 410-500 to the south, to 720m to the east and north (Notestein *et al.*, 1944). A brackish or semi-brackish Mollusca fauna described by Olsson in Notestein *et al.* (1944), 150 m below top the formation near Cúcuta (30km north of Regadera section, 7km NE of Cúcuta), yielded: *Hannatoma* n. sp., *Cerithium* sp., *Harrisianella* cf. *peruviana* Olsson, *Turritella* aff. *chira* Olsson, *Melongena* n. sp, *Cymia* cf. *berryi* Olsson, *Polinices* n. sp., *Anomia* n. sp., *Rhaetomya* sp., *Ostrea* sp., *Pitar* sp., *Clementia peruviana* Olsson, *Mactra* sp., *Tellina* sp., *Phacoides* sp., *Polinices* (*Neverita*)

cf. *subreclusiana* Olsson, *Polinices* sp., *Turritella* aff. *chira* Olsson, *Arca* (*Arginella*) cf. *puntabravoensis* Olsson, *Arca* (*Arginella*) cf. *ocalis* McNeil, *Tagelus* sp., *Corbula* sp. Olsson assigned a middle Oligocene to this assemblage. Durham (1949) added to the assemblage *Arca* (*Argina samanensis*) Olsson?, *Crommium palmarae* Clark, *Hannatoma emendorferi* Olsson, and *Cerithiella* aff. *C. heckscheri* Olsson. Dusenbury (1949) collected in the Cerrito, near Cúcuta, *Pitar (Pitarella) colombiana* Clark, *Neverita bolivarensis* Clark, *Turritella* aff. *chira* Olsson, *Harrissianella peruviana* Olsson, *Cerithium (Perucerithium)* cf. *negritosense* Woods, *Hannatoma emendorferi* Olsson. He also report another assemblage from Quebrada Seca, 9 km NE of Cúcuta, that contains *Arca (Arginella)* cf. *puntabravoensis* Olsson, Ostrea sp., *Mactra* sp., *Pitar* (*Pitarella*) *colombiana* Clark, *Transennella bolivarensis* Clark, *Clementia peruviana* Olsson, *Tagelus bolivarensis* Clark, *Macoma* sp., *Polinices* sp., *Crommium palmerae* Clark, *Turritella* aff. *chira* Olsson, *T. samanensis* Olsson, *Cerithiella* sp., *Harrisianella peruviana* Olsson, *Cerithium* (*Perucerithium)* cf. *negritosense* Woods, *Hannatoma emendorferi* Olsson, *Malanatria* aff. *acanthica* Woods, *Cornulina* sp. 1, *Cornulina* sp. 2, *Perufícus lagunitensis* var. *charanalensis* Olsson, and *Lyria*? sp. Dusenbury (1949) and Durham (1949) re-analyzed the age of the fauna and concluded that the assemblage corresponds to upper Eocene mainly to the presence of *Hannatoma emendorferi*. However, these mollusc faunas are probably related to brackish-water facies making it less reliable for dating purposes. In the area of La Victoria creek (NW Venezuela), Germeraad *et al.* (1968) dated a correlative unit as upper Eocene (pollen zones of *Verrucatosporites usmensis*), in the area of Rubio road it was dated as middle to upper Eocene (upper *Monoporites annulatus* to *V. usmensis* zone). Colmenares and Terán (1993), based on palynology, dated this formation as middle middle Eocene to Oligocene in the Capacha and Delicias sections, Tachira state, near Cúcuta. Unfortunately range charts were not provided

In the Middle Magdalena Valley, the Tertiary sediments are distributed in two units, the Valley itself and the Nuevo Mundo syncline. The northern part of the Valley is bounded by the Mulatos/Cimitarra fault and Central cordillera to the west and the Chucurí flexion to the east (Julivert, 1961; Fabre, 1983). The Salinas fault separates the Nuevo Mundo syncline (where Uribe section is located) from the Valley (Julivert, 1961). Most of Tertiary sedimentation was controlled by syndepositional faults and folds, sediments increase in thickness toward the Salinas fault, and sedimentation is continue in synclines and major unconformities are found in anticlines (Porta, 1974). The stratigraphic nomenclature was a chaos in the first 30-40 years of exploration in the area. Similar names were used for different companies for different units, or different names for same unit. Here, the terminology suggested by Porta (1974) is followed. The Paleocene-Eocene stratigraphy comprises Lisama, La Paz, and Esmeraldas Formations (Porta, 1974).

Lisama Formation was defined by Link in 1925 in a private report and then redefined by Wheeler (Wheeler, 1935). The type locality is located along Lisama creek. Another good exposure is located near Vanegas along Lebrija river, 15 km north from Uribe section (Porta, 1974). It consists of red, gray, brown, and gray shales, with massive muddy sandstone intercalations. Some coal beds are present. Environment is lacunar to deltaic. The thickness of the formation is 1225m in type section, although thickness is extremely variable (Porta, 1974). The lower contact is gradational with Umir Formation (Porta, 1974). The upper boundary is a regional unconformity with El Toro member of La Paz Formation (Porta, 1974). Van der Hammen (1956), Van der Hammen and García (1966), and Germeraad *et al.* (1968) dated the formation as Paleocene (upper *Foveotriletes margaritae*, *Ctenolophonidites lisamae*, and lower *Foveotricolporites perforatus* pollen zones of Germeraad *et al.*, 1968).

La Paz Formation was defined by geologist of the Tropical Oil Co. in Stutzer (1923), and then redefined by Wheeler (1935) and Morales *et al.* (1958). Type locality is

near Vanegas town, along Lebrija river, 15 km north from Uribe section. It consists of gray massive to cross-bedded sandstones, sometimes conglomeratic, with minor intercalations of mudstones and shales mainly in the lower and middle part of the formation. In the lower part, there is a sandy mudstone unit named Miembro Toro, that has an average of 30m in the Mugrose anticline (west part of the basin), although it is extremely variable (Bueno, 1968). The thickness of the formation is 1000m in type section, although thickness is greatly variable (Porta, 1974). The lower contact is unconformable with Lisama Formation (Porta, 1974). The upper boundary is transitional with Esmeraldas Formation (Porta, 1974). Germeraad *et al.* (1968) dated the base of the formation as uppermost Paleocene to middle Eocene (upper *Foveotricolporites perforatus*, *Retibrevitricolpites triangulatus*, and lower *Retitricolporites guianensis* pollen zones).

The Esmeraldas Formation was defined by geologist of the Gulf Oil Co. in Wheeler (1935). Type locality is near Esmeraldas town, close to Sogamoso river, 35km south from Uribe section. It consists of thinly bedded sandstones and gray mudstones interbedded with gray shales occasionally red, purple or brown mottled. Some isolated coal beds are present. The upper part of the formation contains El Chorro fossiliferous horizon. The thickness of the formation is 1200m thickening north (Porta, 1974). The lower contact is gradational with La Paz Formation. The upper boundary is unconformable with the Mugrosa Formation (Porta, 1974), although Morales *et al.* (1958) stated that nature of contact is obscure. Pilsbry and Olsson (1935) dated the El Chorro fauna as upper Eocene based on the fresh to slightly brackish-water molluscan assemblage of *Hemisinus* (s. str.) *corrosensis* Pilsbry and Olsson, *Potamides* (s. lat.) *macgilli* Pilsbry and Olsson, *Diplocyma wheeleri* Pilsbry and Olsson, *D. sucionis* Pilsbry and Olsson, and *Sogamosa cyrenoides* Pilsbry and Olsson (species names are according to the revised determinations of Olsson material by Nuttall, 1990). However, Nuttall (1990) in an extensive analysis of molluscan faunas of northern South America concludes

that there is no molluscan paleontological evidence for the age of Los Chorros fauna to be more precise that "probably Paleogene". Pilsbry and Olsson (1935) based the late Eocene age determination in the inclusion of *Tympanotonus lagunitensis* (Woods) from the Saman Eocene of western Peru in their new genus *Diplocyma*. However, these species are barely similar warranting this inclusion (Nuttall, 1990). Van der Hammen (1958) dated it as upper Eocene based on palynological correlation of his "climatic cycles". Germeraad *et al.* (1968) dated the base of the formation as middle to upper Eocene (*Retitricolporites guianensis* to *Verrucatosporites usmensis* pollen zones).

For the Llanos foothills, the Van der Hammen (1958) nomenclature is followed. He redefines Areniscas de El Morro, Arcillas de El Limbo, Areniscas de El Limbo, and San Fernando in a section along the Cravo river in the Llanos foothills. This stratigraphic nomenclature is followed to avoid the nomenclature often used by oil companies in the Llanos area. Their terminology does not correspond to the original sense of Barco, Cuervos, Mirador and Carbonera Formations as defined in the Catatumbo area (Cooper *et al.*, 1995).

The Areniscas de El Morro Formation was used for the first time in Van der Hammen (1957a), but formally defined by Van der Hammen (1958). Type locality is near El Morro, along Cravo Sur canyon, 100 km NNE of the Piñalerita section. The formation consists of white coarse to medium quartzsandstones, with some intercalation of shales with leaf remains in the middle part. Thickness is 250m in type locality. Palynological analysis of the middle unit indicates an upper Maastrichtian age according to Van der Hammen (1957a) although a species list in support of the age assignment was not provided.

The Arcillas de El Limbo Formation was defined by Hubach in 1941 (in a Shell internal report, according to Van der Hammen, 1958). The type locality is near El Limbo, 2km NW of El Morro, Cravo Sur River, 100km NNE of the Piñalerita section. The formation consists predominantly of gray claystones, some coal beds. Some

sandstones are present in the lower part. The thickness is 250m in the type locality. Lower contact is conformable with the Areniscas de El Morro Formation. Upper contact is conformable with Areniscas de El Limbo (Van der Hammen, 1958). The formation is dated as Paleocene by Van der Hammen (1958), although no data is provided. Cazier *et al.* (1995) and Cooper *et al.* (1995) described a 212m section in the Cusiana field, east of Guaicaramo fault, an area 70km north-northeast of Piñalerita section. They described the section as composed of two intervals. The lower interval (82m thick) is composed of estuarine mouth sand and mud, tidally-influenced estuarine fill, channel-fill sandstones, and muddy bioturbated estuarine deposits. They called this interval "Barco" Formation. The upper interval (132m) is composed of muddy, lower coastal plain deposits that they called "Cuervos" Formation. Although no paleontological evidence is provided, they dated Barco as late Paleocene (Cazier *et al.*, 1995) and Cuervos as early Eocene (Cazier *et al.*, 1995) or late Paleocene (Cooper *et al.*, 1995). Is this "Barco" correlated with the upper segment of Areniscas de El Morro or is it correlated with lower Arcillas de El Limbo?. Although these two areas, Morro and Cusiana, are very close to each other (40km apart), they are separated by Guaicaramo fault, a major fault that has had significant lateral and orthogonal transport (Dengo and Covey, 1993; Montes personal communication). In Cusiana, "Barco" is marginal marine and 82m thick and "Cuervos" is coastal plain and 132m thick. In El Morro, on the other hand, the upper portion of Areniscas de El Morro is fluvial and approximately 120m thick, and the Arcillas de El Limbo are coastal plain and 250m thick. These data indicate how complex the geology of the area is, especially because strata along the hanging wall of the Guaicaramo fault have had significant horizontal displacement that has put in close contact facies that originally were separated by tens of kilometers. This could produce large thickness, facies, and age changes in small area. Also, clearly the lack of published data supporting age assignments has created an enormous confusion when correlating formations.

Guerrero and Sarmiento (1996) propose to use the stratigraphical terminology of the Boyaca region in eastern Cordillera for the Llanos foothills. They correlate the Socha Inferior Formation (dated as late Paleocene based on pollen and spores) with the upper segment (~120m) of Areniscas de El Morro. However, I do not follow their suggestion because of the following reasons: The age for the upper portion of Areniscas de El Morro is unknown, Socha inferior has not been very well dated in the type section at Chicamocha (Sarmiento and Alvarado, 1944 in Porta, 1974), the Paleogene sequence in Boyaca contains the oolitic ironstone of the Concentration Formation, that is not present in the Llanos foothills. It could be argued that underlying formations (Socha Inferior and Socha Superior) do not have lithological continuity in the Llanos Foothills as well. Finally, Guerrero's approach could lead to an oversimplification of the geology of the area.

The Areniscas de El Limbo Formation was defined by Hubach in 1941 (in a Shell internal report, according to Van der Hammen, 1958). The type locality in near El Limbo, 2km NW of El Morro, Cravo Sur River, 100km NE of the Piñalerita section. The formation consists predominantly of conglomeratic sandstones with a middle shaly unit. The thickness is 270m in the type locality. Lower contact is conformable with Arcillas de El Limbo Formation. Upper contact is conformable with San Fernando Formation (Van der Hammen, 1958). Formation was dated as lower to middle Eocene by Van der Hammen (1958), although no data was provided. Cazier *et al.* (1995) and Cooper *et al.* (1995) described a 131m section in the Cusiana field, east of Guaicaramo fault, an area 70km north-northeast of Piñalerita section. They described it as composed of three intervals, the lower unit composed of medium-coarse, mature, quartz sandstone of estuarine channel-fill deposits. The middle unit is composed of muddy marine, interdistributary bay, and nonmarine floodplain deposits. The upper unit contains estuarine and distributary channels sandstones and minor mudstones. They named this formation "Mirador", and dated it upper Eocene, although no data was provided in

support of this conclusion. They stated that their use of Mirador does not correspond to the original term defined in Maracaibo Basin.

San Fernando Formation was defined by Hubach in 1941 (in a Shell internal report, according to Van der Hammen, 1958). The type locality is in the north part of La Macarena range in the Hernandez plateau, 180km SW of the Piñalerita section. Van der Hammen, however, describe the section from El Limbo, 2km NW of El Morro, Cravo Sur River, 100km NE of the Piñalerita section. The formation consists predominantly of mudstones. Paba-Silva and Van der Hammen (1958) dated it as upper Eocene-lower Oligocene based on palynology although no supporting data was presented. Hopping (1967) and later Germeraad *et al.* (1968) also uses the term San Fernando Formation in some areas of the Llanos area. They used in the stratigraphy of two wells: Voragine-1 and Chafurray-3. It consists of a brackish, coastal plain muddy unit. It is overlaid by Orteguaza Formation but its lower contact is unknown. Germeraad *et al.* (1968) dated this unit as Late Eocene to early Oligocene (upper *Verrucatosporites usmensis* to lower *Cicatricosisporites dorogenis* pollen zones). Germeraad *et al.* (1968) also used the term for a lithological section in the Cobugón river near the Venezuela frontier. It is unclear if this section corresponds to the same unit as defined in the type section (320 km apart). Porta (1974) recommended to limit the term to the type section area and closely localities. I used the term following Van der Hammen (1958) and its description in the Morro. Cazier *et al.* (1995) and Cooper *et al.* (1995) described a 1.3km section in the Cusiana field, east of Guaicaramo fault, an area 70km north-northeast of Piñalerita section. They described the formation as composed of several (four) intervals composed of a muddy unit capped by a sandstone, accumulated mainly in coastal plain. They called it "Carbonera" Formation, and dated it as uppermost Eocene to early Miocene (no data provided). This "Carbonera" does not correspond, however, to the original term defined in Maracaibo Basin (Cooper *et al.*, 1995).

In order to produce a paleobathymetric curve that can be used in the sequence stratigraphic analysis of each section, lithological characteristic must be used to interpret environments of accumulation. Here, the ideal facies models of Galloway and Hobday (1996) were used in order to interpret the gross depositional systems for each studied sections. The purpose of the lithological analysis was to interpret the overall trend in gross depositional environments that could be related to changes in base level and therefore placed in a sequence stratigraphy framework.

Major clastic environments that could be represented in the studied section were classified according to Galloway and Hobday (1996) in 3 major environments: fluvial, deltaic and estuarine (Figs. 6-12, 6-13. 6-14). Fluvial environments were divided in bed-load channel, mixed-load channel, and suspension-load channel environments. Delta systems were divided into delta plain, delta front (tide, wave, or fluvial dominated), and prodelta. Estuaries were divided into shoreface and beach, barrier islands/tidal deltas, and tidal flat/tidal channels/estuary fills/lagoon environments. A brief description of each environment is shown in Figures 6-12, 6-13, and 6-14 along with the major lithologic characteristics that were used to infer the environments of accumulation for the sections studied.

Results

Description of the lithology and interpretation of the sedimentary environments are shown in Appendices B, C, and D, and Figures 6-15, 6-16, 6-17.

Piñalerita section. The Piñalerita section is divided into several intervals described below from bottom to top (Appendix B, Fig. 6-15).

Interval -2 to 0m, top Arenisca de El Morro Formation. This interval is characterized by white fine to medium-grained, well sorted, quartz-sandstones, with planar and trough-cross bedding, and no evidence of bioturbation. These deposits

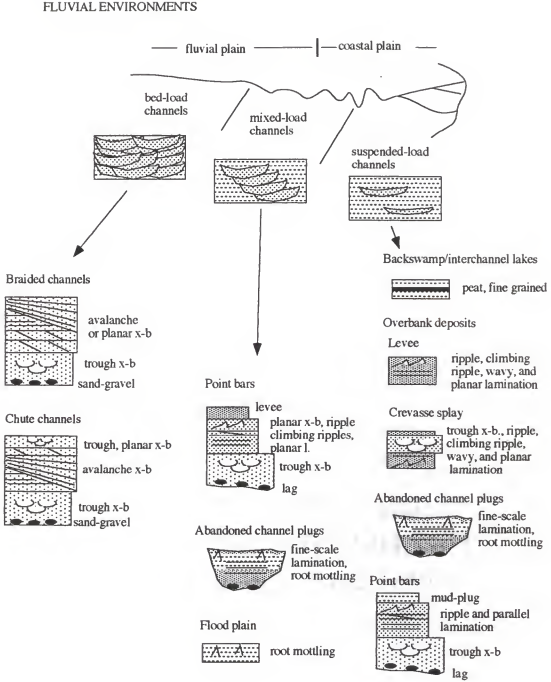


Figure 6-12. Schematic representation of the major divisions of fluvial environment used in the lithological interpretation (adapted from Galloway and Hobday, 1996).

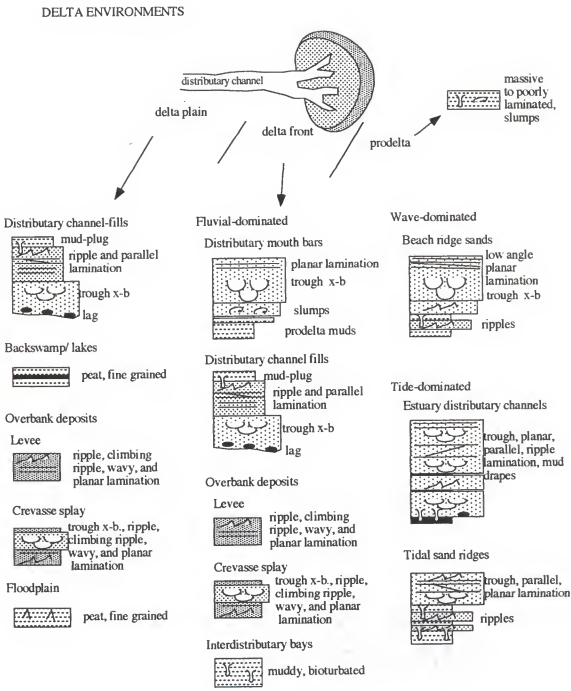


Figure 6-13. Schematic representation of the major divisions of delta environment used in the lithological interpretation (adapted from Galloway and Hobday, 1996).

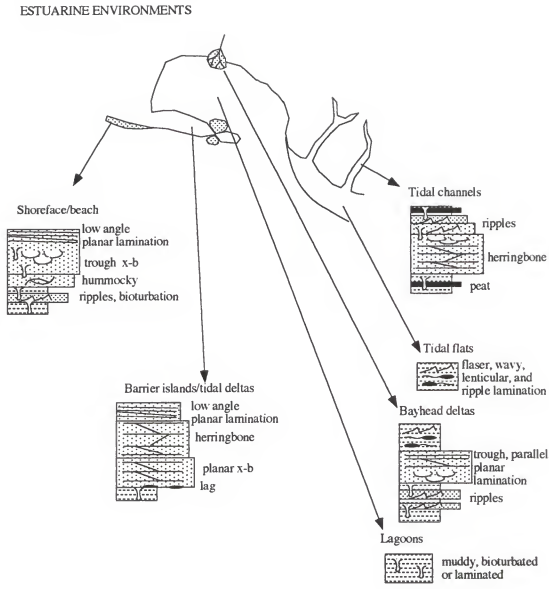


Figure 6-14. Schematic representation of the major divisions of estuary environment used in the lithological interpretation (adapted from Galloway and Hobday, 1996)

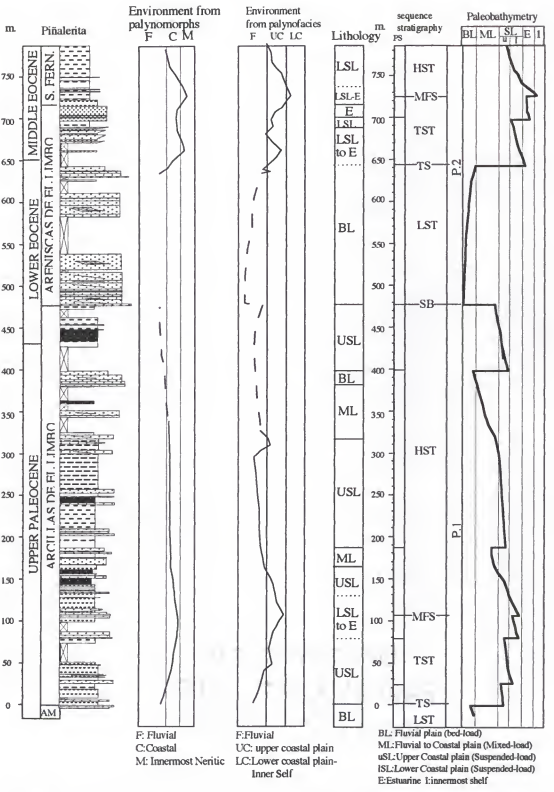


Figure 6-15. Sequence stratigraphic interpretation for Piñalerita section based in lithofacies interpretation, paleonvironment from palynofacies, and paleoecology. Key for lithological symbols in Appendix B.

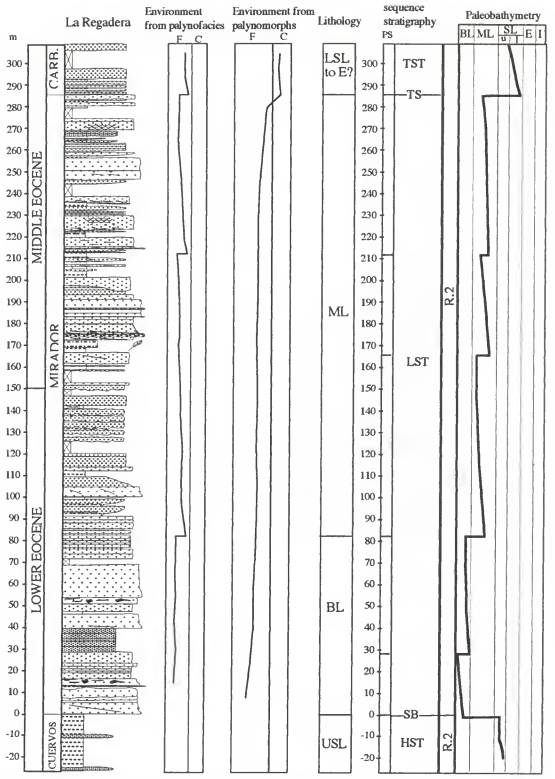


Figure 6-16 Sequence stratigraphic interpretation for Regadera section based in lithofacies interpretation, paleonvironment from palynofacies, and paleoecology. Key for symbols in Appendix C, and Figure 6-15.

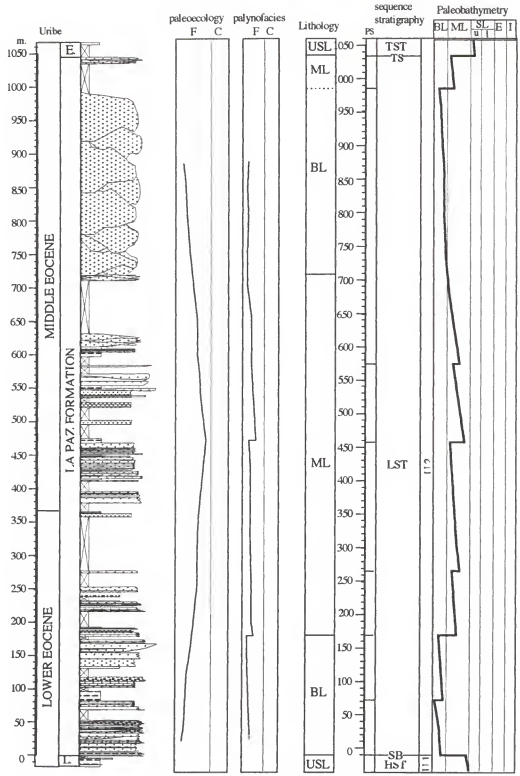


Figure 6-17 Sequence stratigrphic interpretation for Uribe section based in lithofacies interpretation, paleonvironment from palynofacies, and paleoecology. Key for symbols in Appendix D and Figure 6-15.

indicate high energy flows suggesting braided or chute channels-fills in bed-load channels environments of the fluvial plain.

Interval 0-117m, lower Arcillas de El Limbo Formation. It is characterized by dark green to gray mudstones, generally light green to silty red to light gray mottled, sometimes burrows are evident. These fine units are interbedded with three sandstones units (5-10m thick) characterized by slightly upward fining grain patterns of coarse to medium lithic to quartzsandstones with planar and trough cross bedding, planar lamination, muddy intraclasts, bioturbated at the base of the channels. These characteristics suggest deposition in estuary distributary channel-fills and tidal sand bars in small bay head deltas in the estuary zone. The base of each sand body seems to indicate a flooding event on the coastal plain (bay head abruptly overlying coastal plain deposits) and here is interpreted as the base of a parasequence. In general this first interval corresponds to lower coastal plain to estuarine environments (Figs. 6-14, 6-16) according to the facies model described above (after Galloway and Hobday, 1996).

Interval 117m to 186m, lower Arcillas de El Limbo Formation. This segment is divided into two units: 117-162m, and 162-186m. The first unit (117-162m) is characterized by green to gray mudstones, with scatter plant remains, and occasionally plane-parallel lamination. Thinly bedded intercalations of muddy sandstone with ripple lamination are present. Toward the upper part of the segment there is an increase in purple to gray claystones. This unit suggests suspension-dominated channel environments of the coastal plain. The second unit (162-186m) is dominated by fining-upward lenticular beds of medium to fine sandstones with trough and planar cross-bedding, plane-parallel and ripple lamination, capped by coals and thinly bedded muddy sandstones. This lithology suggests point bars, levees and floodplain subenvironments of a mixed-load channel system in the fluvial to lower coastal plain (Figs. 6-12, 6-16). This unit corresponds to a parasequence.

Interval 186m to 399m, upper Arcillas de El Limbo Formation. This segment is divided into three units: 186-318m, 318-381m, and 381-399m. The first unit (186-318m) is dominated by dark to light gray claystones with scattered sandy pellets, interbedded with thinly bedded fine sandstones with ripples and trough cross-bedding. Mottled green to purple claystones are more common toward the top of the unit. This lithology suggests suspended-load channels in the upper Coastal Plain environment. Next unit (318-381m) is dominated by medium to fine-grained lithic sandstones with planar and trough cross-bedding and ripple marks, interbedded with light green claystones. This suggests mixed-load channels in the fluvial to lower coastal plain environment. The next unit (381-399m) is dominated by very coarse to coarse lithic sandstone, massive, with large-scale trough and planar cross-bedding, and conglomeratic lenses with chert and quartz fragments. This lithology suggests high-energy deposition as in braided or chute channel-fills in bed-load channels of the fluvial plain environment. These three units constitute a single prograding cycle (parasequence).

Interval 399-477m, upper Arcillas de El Limbo Formation. It is dominated by green to purple claystones, intensely red-mottled, interbedded with a few, thinly bedded siltstones. This lithology suggests suspension-load channels of the upper coastal plain environment.

Interval 477-643m, lower Areniscas de El Limbo Formation (meters 0 to 166 of formation). Ii is dominated by well sorted, coarse, thick bedded, mature, massive, white to yellow quartz sandstone, with conglomeratic intervals and large scale trough and planar cross bedding. This lithology indicates high energy deposition in bed-load dominated channels in the fluvial environment.

Interval 643-714.6m, upper Areniscas de El Limbo Formation (meters 166 to 237.6). It is subdivided into three units. First unit, 643-689m (meters 166 to 212), is characterized by coarsening-upward, massive, medium to fine quartz sandstone beds with intense bioturbation (*Thalassinoides* among others), interbedded with bioturbated dark

gray mudstones. This lithological assemblage suggests small bayhead deltas in estuarine environments. Second unit, 689-699.5 (meters 212 to 222.5), is dominated by a gray mudstone with plane-parallel lamination suggesting floodplain to coastal lakes in suspended-load channels in lower coastal plain environment. Third unit, 699.5-714.6 (meters 222.5 to 237.6), is characterized by black mudstone with flaser lamination, leaf remains, *Thalassinoides*, fine sands, thinly bedded with trough cross bedding and ripples marks. This lithological assemblage suggests tidal flats in an estuarine environment. Units 1 and 2 form a prograding unit (parasequence).

Interval 714.6-786.6m lower San Fernando Formation (meters 0 to 72). It is subdivided into three units. First unit, 714.6-721 (meters 0 to 6.4 of San Fernando Formation), is a black mudstone. Second unit, 721-743 (meters 6.4 to 22), is dominated by green to gray claystone with scattered thin-bedded siltstone beds, and possible a thin layer of phosphorite. This lithology suggests suspension-load dominated channels in lower coastal plain to estuarine conditions. Third unit, 723-786.6 (meters 22 to 72) is characterized by a monotonous lithology of green claystones suggesting suspension-load dominated channels in lower coastal plain environments.

Regadera section. Regadera section is divided into three intervals described below from the bottom to the top (Appendix C, Fig. 6-16).

Interval -70m to 0m, upper Carbonera Formation. This interval is characterized by light gray to purple mudstone, with red to green mottling, interbedded with thin-bedded green fine-grained lithic quartzarenite with ripple lamination, and very fine-grained massive green lithic arenite and purple siltstones. This lithology suggests floodplain and overbank deposits of suspension-load dominated channels in the coastal plain environment.

Interval 0-82m, lower Mirador Formation. This interval is dominated by thick-bedded, white quartzarenite, fairly sorted, with large scale planar, trough cross-bedding to

massive, and planar lamination, conglomeratic beds, intraclasts, interbedded with fine to very fine-grained lithic quartzarenite, dark gray to green with plane-parallel lamination. This lithology suggests high energy environments as braided/chute channels in bed-load dominated channels of the fluvial plain environment. Two parasequences could be recognized (0 to 28m, and 28 to 82m) that indicate a net progradation of the system (more coarser-grained channel-fills toward top of parasequence) and are overlaid by a minor transgression but within the bed-load environment (Fig. 6-16).

Interval 82-285.5m, upper Mirador Formation. This interval is dominated by thin-bedded fine gray lithic quartzarenite with ripple and discontinuous lamination interbedded with claystones, and dark gray upward-finning medium to fine arenites, with gravel lags, trough and planar cross-bedding capped by ripple and plane-parallel lamination. Scattered thin coal layers are present as well as light gray claystones with some mottling (bioturbation?), and isolated lenticular bodies of very fine-grained gray arenite with ripple lamination. This lithological assemblage suggests point bars, overbank and floodplain deposits of mixed-load channels in the fluvial environment. Three parasequences could be recognized (82 to 165m, 165 to 211m, and 211 to 285.5m). They indicate a net progradation of systems (fine to the base, and more sandy to the top of the parasequence). First and second parasequence (82 to 165m, 165 to 211) are overlaid by a minor flooding within mixed-load system, the third is overlaid by a major flooding (at 285.5m).

Interval 285.5-307.5m, lower Carbonera Formation. It is characterized by thinly bedded fine-grained lithic quartzarenites, with lenticular lamination, and abundant burrow trails. This lithology suggests overbank deposits in areas with marine influence in lower coastal plain to estuarine? environments.

Uribe section. Uribe section is divided into 4 intervals described below from bottom to top (Appendix D, Fig. 6-16).

Interval -14 to 0m, upper Lisama Formation. This interval is dominated by purple claystone, red mottled, that suggest floodplain sediments of suspended-load dominated channels in the upper coastal plain.

Interval 0-180m, lowermost La Paz Formation. It is characterized by clast-supported polymictic conglomerates, massive coarse-grained lithic arenites, thick bedded, and large scale planar and trough cross-bedding that indicates high energy deposition in braided/chute channels in bed-load channels of the fluvial plain environment. Two prograding units (parasequences) could be recognized: 0 to 84m, and 84 to 180m. Both are within bed-load environment, and have purple to red claystones toward base and coarser material toward the upper part of parasequence.

Interval 180-585m, lower La Paz Formation. This interval is divided into three units: 180 to 255m, 255 to 466m, and 466 to 585m. The first unit (180-255) is dominated by fine to medium-grained lithic arenites, thin-bedded, with plane-parallel lamination interbedded with red claystones, and thin coal beds. The second unit (255-466) is characterized by medium lithic arenites with trough cross-bedding interbedded with black shales and thin-bedded, very fine-grained lithic arenites and several covered intervals that probably are fine-grained because they produced valleys in topography. The unit has toward the top thin to medium-bedded, medium to coarse-grained lithic arenites with planar cross-bedding, and isolated lenticular arenite bodies in dark shales. The third unit (466-585) is dominated by red to brown claystones in the lower part, and fine-grained lenticular quartzarenites, thin-bedded and amalgamated that are interbedded with fine quartzarenites with lenticular lamination and upward-fining channel-fills with gravel lags, and trough and planar cross-bedding. These three units indicate floodplain, overbank deposits, and point bars in mixed-load dominated channels of the fluvial environment. Each unit represent a net progradation (parasequence) with fine grained facies in the lower part and coarser facies toward the upper part of the unit.

Interval 585-989m, upper La Paz Formation. Most of this interval is not exposed or is poorly exposed. The first 134m (585-719) are poorly exposed and dominated by light gray claystones interbedded with thin-bedded, medium-grained lithic arenites. This lithology suggest mixed-load dominated channels of the fluvial environment. The upper 270m (719-989) are dominated by coarse to medium-grained quartzarenites, with large scale trough and planar cross-bedding, and conglomeratic beds with scarce presence of fine sediments. This lithology indicates bed-load dominated channels of the fluvial environment. The whole interval constitutes a parasequence.

Interval 989-1046m, uppermost La Paz Formation. Lower part of this interval is covered and probably is fine-grained sediment (gives a topographic low), toward the top outcrops a massive, medium-grained quartzarenite, in amalgamated lenticular bodies. This lithology suggests mixed-load environments of the fluvial plain.

Interval 1046-1066m lowermost Esmeraldas Formation. It is dominated by purple mottled light gray claystones suggesting floodplains in suspended-load dominated channels of the upper coastal plain environment.

Sequence Stratigraphy Interpretation

Previous Studies

Sequence stratigraphy is relatively new field in Colombian geology. Very few studies has been published on sequence stratigraphy of Paleocene-Eocene strata in Colombia. Most of the sequence stratigraphic analysis are produced by oil companies and remain unpublished or are only presented as abstracts for symposia (e.g., Middle Magdalena area: Ramon and Cross, 1996; 1997; Suarez, 1997a; 1997b; Villamil and Restrepo-Pace, 1998; Llanos foothills: Pulham, 1995; Fajardo and Cross, 1996; Pulham *et al.*, 1996; Pulham *et al.*, 1997; Llanos: Malagon, 1997; Aurisano, 1998). Four papers have addressed sequence stratigraphy interpretations for Paleocene-Eocene strata in Colombia: Cooper *et al.* (1995), Cazier *et al.* (1995), Guerrero and Sarmiento (1996), and

Vergara and Rodriguez (1997). The first three papers are results from exploration by the British Petroleum Company in the recently discovered giant oil field of Cusiana in Colombian Llanos foothills.

The following is a brief summary of the sequence stratigraphy presented by Cooper *et al.* (1995) with additional data from Cazier *et al.* (1995, 1997). Cooper divides Paleocene-Eocene strata in three sequences (T10, T20, and T 30) grouped in two Pre-Andean Foreland Basin megasequences (Fig. 6-18). The first megasequence includes sequences T10 and T20. This megasequence starts with the development of the Pre-Andean Foreland Basin produced by the accretion of the western cordillera that ended the back-arc Cretaceous marine deposition (Dengo and Covey, 1993). This orogenesis was active in maintaining a topographic high and sediment source in the Central and Western Cordilleras for the foreland basin developed east of Central Cordillera during most of the Mesozoic (Dengo and Covey, 1993). The depositional axis of this foreland basin was initially the Middle and upper Magdalena valleys, migrating with time toward the east to the actual position along the western margin of Llanos area (Villamil and Restrepo, 1998).

The T10 sequence (Fig. 6-18) is dominated in the Eastern Cordillera by coastal and alluvial-plain deposits of the Guaduas Formation that is dated as late Maastrichtian to early Paleocene (Sarmiento, 1992). This sequence is not present in the Llanos area or the Llanos foothills east of the Guaicaramo fault being correlative with a hiatus in those areas spanning the Cretaceous-Tertiary boundary. The T10 sequence shows a general northward and eastward thinning. T10 is present west of Guaicaramo fault suggesting some degree of fault control on T10 deposition by differential subsidence across the fault. In the Middle Magdalena, T 10 is represented by shales and sands (Lisama Formation).

Next sequence is late Paleocene T20 (Fig. 6-18). Transgression and loading of protoforeland basin due to deformation in Central and Western Cordilleras reinstalled deposition on Llanos foothills and across Llanos area during this sequence. Barco

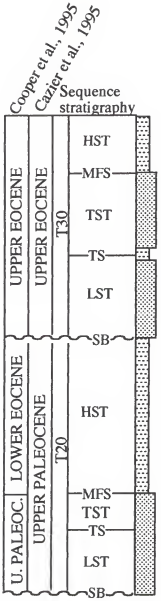


Figure 6-18. Cooper *et al.* (1995) and Cazier *et al.* (1995) sequence stratigraphic model for Paleocene-Eocene Colombian sedimentary strata

Formation forms a basal transgressive systems tract (TST). It is a sand-rich, estuarine, Guyana shield-derived deposit. Basal T20 is present in Llanos foothills, Eastern Cordillera (part of Socha Formation), and Middle Magdalena Valley. In the Llanos foothills this basal T20 is called Barco Formation. It includes from the base, muddy bioturbated estuarine deposits, overlain by tidally-influenced estuarine channel-fill sandstones, followed by progradational estuary mouth sandstones and mudstones (Cazier *et al.*, 1995). This succession, approximately 82m thick, suggest TST and HST filling one or more incised valleys that intergrades transitionally with the overlying Cuervos Formation (Cazier *et al.*, 1995).

Following the transgressive systems tract (TST) of T20, a highstand systems tract (HST) developed and shoreline migrated westward producing an extensive regression in Eastern Cordillera and Llanos foothills (Cuervos, Bogota, and Picacho Formations). In the Llanos foothills this HST constitutes the Cuervos Formation, a muddy section accumulated in lower coastal plain environments, approximately 132m thick (Cazier *et al.*, 1995) and dated as upper Paleocene (Cooper *et al.*, 1995) or lower Eocene (Cazier *et al.*, 1995) in the Cusiana field.

A major drop in relative sea level occurred at top of T20 (54 my-earliest Eocene) resulting in a shift of deposition to the west and north and a major sequence boundary. In the Llanos it resulted in a disconformity (without angular component) that encompass 16 my (early-middle Eocene). It also produced thrusts and folds in upper Magdalena Valley. Earliest middle Eocene sediments are absent in Colombia due to deformation that Cooper relates to change in direction and rate of subduction of Nazca Plate (Pardo-Casas and Molnar, 1987; Daly, 1989). Between anomalies 21-18 (early to late middle Eocene), the Nazca-South American convergence increased to 164 +/- 65 mm/a at the latitude of Perú and 204+/- 80mm at latitude of Ecuador (up from 55 +/- 28 mm/a during anomalies 30-31 to 21: Maastrichtian to latest early Eocene) and perhaps a few millions years before and after this interval (Pardo-Casas and Molnar, 1987; Daly, 1989). Between anomalies 30-

21 (Maastrichtian to latest early Eocene) the Nazca plate seems to have rotated about a pole in southern South America so that it converged with northern South America. By the beginning of anomaly 21, the Nazca plate started to converge less obliquely with the South American plate (Pardo-Casas and Molnar, 1987). There is a correlation of this rapid convergence with the late Eocene Incaic phase of intense tectonic activity in Perú (Pardo-Casas and Molnar, 1987) and the formation of a major pull-part basin in Ecuador forearc (Daly, 1989). However, rapid convergence alone is not a sufficient condition for Andean margins to be built, a young ocean floor is also necessary. Unfortunately, age of ocean floor subducted beneath South America before 25 Ma is still unknown (Pardo-Casas and Molnar, 1987).

The late Pre-Andean Foreland Basin started with "sequence" T30. For this interval, Cooper is using Galloway's concept of sequence (a genetic stratigraphic unit bounded by maximum flooding surfaces, Galloway, 1989), instead of sequence concept (bounded by sequence boundaries, Van Wagoner *et al.* 1990) that Cooper used for T10 and T20. Deposition in the Llanos started again in the latest middle Eocene (~40.5 my) due to a regional transgression that spread southward and eastward from the foreland basin. T30 onlapped much farther east on Guyana shield than T20. Initial T30 in the Llanos Foothills (Mirador Formation) is dated as ~38my (late middle Eocene) and consisted of mature quartz-arenites of fluvial and estuarine valley-fill deposits contained in muddier coastal plain deposits (Cazier *et al.*, 1995). Mirador in Cusiana area is ~131m thick. It is divided in three subunits. The lower subunit is a medium to coarse sandstone deposited in estuarine channel fills of a number of valleys that incised in an aggrading coastal plain (Cazier *et al.*, 1995). These strata contain brackish ichnofacies as *Ophiomorpha*, *Planolites*, *Teichichnus*, *Thalassinoides*, *Diplocraterion*, *Paleophycus*, *Macaronichus*, *Gyrolithes*, *Planolites*, and *Arenicolites* (Cazier *et al.*, 1995, 1997). This lower Mirador unit is succeeded by a muddy marine interdistributary bay and nonmarine floodplain deposits that form a middle shale unit in Cusiana, and in the Llanos area

(Cazier *et al.*, 1995). This muddy unit is overlain by the upper Mirador, a succession of intensely bioturbated coarser grained estuarine and distributary channel sandstones, and minor mudstones that become more marine until marine flooding at ~34 my (latest late Eocene) that ended T30 "sequence" (Cazier *et al.*, 1995). This marine flooding is identified by dinoflagellate cysts such as *Spiniferites*, *Polysphaeridium*, *Operculodinium*, *Cordosphaeridium*, *Homotryblium*, *Cribroperidinium*, and *Hystrichokolpoma* (Cazier *et al.*, 1997). On the Llanos, it is dominated by fluvial and alluvial fan coarse sandstones ranging from 152 to 61m thick (Mirador Formation), although in the area of Caño Limón (northeastern Llanos) it has been interpreted as a 80m thick, series of medium to coarse sandstones accumulated in a mainly river-dominated delta system, with several marine shales, delta fringe sands, and probably wave-dominated deltas, 80m thick (Cleveland and Molina, 1990; McCollough and Carver, 1992), and dated as early to late Eocene (Cleveland and Molina, 1990, Fig.12-7, p. 289) although supporting data is not provided. T30 deposits are called Gualanday, La Paz, and Esmeraldas Formations in Magdalena Valleys and occur over a dramatic angular unconformity, although has been reported only in subsurface anticlines the west side of the Valley (Julivert, 1961). T30 thickness is extremely variable due to fault control or by westward thickening into foreland basin. T30 ended with a maximum flooding surface(MFS) at ~34 my-latest late Eocene.

After T30, four major cycles (T40-T70) of lower coastal plain sediments, marine-influenced, accumulated in Llanos area and Llanos foothills (Cazier *et al.*, 1995). Each "sequence" is composed of a muddy HST, a thin forced regression (LST), and a sandy TST. These are called Carbonera Formation in the Llanos area (approximately 1.3km thick), upper Esmeraldas, Mugrosa, Colorado, and La Cira in Middle Magdalena Valley, and Concentración in the Eastern Cordillera. Upper T70 is dated as 16.5 my (early Miocene). This "sequences" record easterly migration of foreland basin subsidence that culminated with onset of Eastern Cordillera deformation. T30-T70 sources are Guyana shield, and parasequences were prograding westward into basin. T40-T70 cycles were

produced while Nazca-South America convergence was slower (anomalies 13 to 7, rate: 50+/-30mm/y at the latitude of Perú; 44+/-26 mm/y at the latitude of Ecuador) and probably tectonic activity was also relatively quiescent (Pardo-Casas and Molnar, 1987; Daly, 1989). However, it seems contradictory that quiescent times during T40-T70 produced fine sediments instead of coarse sediments as low generation of accommodation space would predict (Posamentier and Allen, 1993). The same argument could be used for T30 deposition, that was a period of fast convergence that probably would increase the generation of accommodation space and, however, extensive arenites are deposited.

Higgs (1997) challenged some of the interpretations of Cooper *et al.* (1995). He disagreed in the marine influenced interpretation for environments of Barco (lower T20) and Mirador (T30) Formations. According to Higgs (1997) data presented by Cooper does not fully support the estuarine interpretation, and ichnofossils interpreted as indicating marine influence can also be found in fluvial deposits. Also, Higgs did not find any evidence of marine influenced deposits in correlative formations in western Venezuela, which according to paleogeographic interpretations of Cooper should be found. However, as Cazier *et al.* (1997) pointed out, published biostratigraphic data from southwest Venezuela, Colombian Llanos foothills, Eastern Cordillera, Middle Magdalena Valley and the Llanos areas is very scarce, making correlations based on formational names very uncertain. Probably the Mirador Formation in Llanos foothills is not lateral equivalent of either Mirador or Guafita Formation in southwestern Venezuela (Cazier *et al.*, 1997) and it is possibly younger (McCollough and Carver, 1992). A clear picture of either sequence stratigraphy or paleogeography of Paleocene-Eocene deposits is still elusive, although the conceptual model presented by Cooper *et al.* (1995), and Cazier *et al.* (1995) and (1997) are appropriated working hypothesis upon which improved interpretations can be done as more data is added, especially biostratigraphic.

Guerrero and Sarmiento (1996) and Vergara and Rodriguez (1997) only addressed Paleocene strata (Fig. 6-19). Guerrero and Sarmiento (1996) propose a sequence ST2,

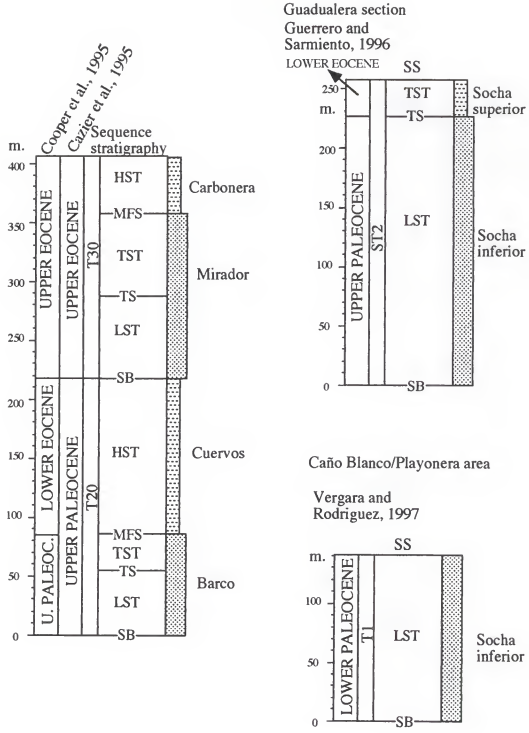


Figure 6-19. Previous sequence stratigraphic models for Colombian Llanos foothills

that is bounded by a sequence boundary encompassing the late Maastrichtian and early Paleocene. This sequence starts with a lowstand systems tract (LST) that correspond to the Socha inferior Formation in the Guadualera section (30 km west of Piñalerita section). This LST is characterized by braided stream deposits. It is dated as late Paleocene based on palynomorphs. The Socha inferior is capped by a TS, that correspond to the Socha inferior-superior boundary; the lower Socha superior is dominated by coastal plain shales and it is dated as early Paleocene based on palynology.

Vergara and Rodriguez (1997) also proposed a sequence, T1, that is bounded at the base of the Socha inferior in the Playonera (~10km northwest of Piñalerita section) and Caño Blanco sections (~130km southwest of Piñalerita). The Socha inferior is interpreted as a lowstand system tract (LST). The lower part of the formation is dominated by braided-stream deposits, specially in Caño Blanco area, while the upper part is characterized by arenites with bidirectional curved lamination, with a few coal beds, black mudstones, and fine sandstone-mudstone intercalations that are interpreted as estuarine distributary channels in estuarine environments. This LST is dated as early Paleocene based on palynology, (taxon lists for individual samples are reported in Vergara and Rodriguez , 1997).

Rull (1997b) attempted a sequence stratigraphic analysis of two cores in western Venezuela. Using palynomorphs distribution, he proposed more than 12 sequences for the late Paleocene-Eocene interval in the Maracaibo area. Some of the "sequences" do not have either maximum flooding surface (MFS) or transgressive surface (TS), and consist of sequence boundaries (SB) stratigraphically very close to each other, in other cases the "sequence" only contains 2 consecutive MFS. He does not present any lithological, seismic, or paleontological evidence that support his proposed sequences. He used major changes in palynoflora or barren intervals with oxidized kerogen as indicative of sequences boundaries. However, these palynological changes may also be due to climatic changes affecting flora, or laterally changes in depositional environments

(e.g., channel to overbank deposits) rather that a drop in either relative or eustatic sea level. Then, he correlated them to the Haq *et al.* (1988) cycle chart obtaining a relatively good correlation. However, Pindell and Drake (1998) have shown the dominant tectonic control on the architectural development of the basin, that largely overprint the 3rd order eustatic cycles of the Haq *et al.* (1988) chart. This makes highly suspicious the good correlation of Rull's "sequences" and Haq's cycle chart. The degree of influence of the chart on Rull's interpretation is not known but appears to be high.

Results

The three sources of information (palynofacies, palynomorph paleoecology, and lithology) were combined to produce a paleobathymetric curve and sequence stratigraphic interpretation for each section (right side of Figs. 6-15, 6-16, 6-17).

Piñalerita section. Five important surfaces were identified in this section (Fig. 6-15). The first one is a transgressive surface (TS) at 0 meters (Areniscas de El Morro-Arcillas de El Limbo boundary). This contact is sharp and characterized by bed-load deposits overlaid by suspended load deposits, indicating a rapid increase in accommodation space that can be produced by a rise in base level (Van Wagoner *et al.*, 1990). The second surface, at 105 meters, is interpreted as a maximum flooding surface (MFS). It is characterized by the onset of a bayhead delta onto coastal plain sediments, with well-preserved terrestrial dispersed organic matter and a high abundance of Paleocene coastal plain elements (e.g., *Proxapertites*). It also recognized by being the boundary between a retrograding parasequence stacking below and a prograding parasequence stacking above (Fig. 6-15). The third surface is identified as a sequence boundary (SB) at 477 meters, at the Arcillas de El Limbo-Areniscas de El Limbo boundary. It is characterized by a 1m red claystone that is probably a paleosoil. This surface puts in contact suspension-load deposits of the upper coastal plain below and bed-

load deposits above indicating a fast facies regression product of a drop in base level (Van Wagoner *et al.*, 1990). The fourth surface is a TS at 643m, upper Areniscas de El Limbo Formation. Bed-load deposits below and lower coastal plain to estuarine deposits above characterize this surface. The exact location of this surface is tentative because there is a 17.5m covered interval that is immediately below a mudstone sample (660.5m) that contains abundant dinoflagellate cysts and well-preserved dispersed organic matter with marine influence, and immediate above arenites of bed-load environments with palynomorphs and organic matter that indicate fluvial environments (paleoecological group G, palynofacies 6). Therefore, TS could be anywhere within the interval 643-660m, but here is assumed 643m because the covered interval could be a mudstone, similar to facies of 660.5 m sample, that would suggest that flooding occur immediately above 640-642m arenite. The last surface is a MFS at 725m and it is identified because of a high abundance and diversity of dinoflagellate cysts (paleoecological group G), well-preserved dispersed organic matter (palynofacies group 5), fine lithology (gray claystone), and a retrograding parasequence stacking below and a prograding parasequence stacking above.

Based on these five surfaces and the parasequence stacking pattern (prograding versus retrograding) (see Fig. 6-15), two sequences and 6 systems tracts were recognized. Sequence P.1 is composed of a lowstand system tract (LST) in the upper Areniscas de El Morro, a transgressive systems tract (TST) in the lower Arcillas de El Limbo Formation (0 to 105 meters), and a highstand systems tract (HST) in the upper Arcillas de El Limbo Formation (105-477 meters). The second sequence P.2, 477-643m, is composed of a LST in the lower Areniscas de El Limbo Formation (lower 166m); a TST, 643-725m, in upper Areniscas de El Limbo (upper 71.6m) to lowermost San Fernando (lower 10.4 m) Formations; and a TST, 725-786.6m, lower San Fernando Formation (meters 10.4 to 72).

Regadera section. Two important surfaces were identified in this section (Fig. 6-16). The first surface is identified as a MFS at 0 meters, Cuervos-Mirador contact. It is characterized by a red mudstone (paleosoil), and an abrupt facies change from suspension-load deposits of the upper coastal plain below to bed-load deposits of the fluvial plain above. This abrupt facies change indicates a sequence boundary (Van Wagoner *et al.*, 1990). The next important surface is at 285.5m, Mirador-Carbonera contact, and is recognized as a transgressive surface (TS). It is characterized by a fast facies change from mixed-load to suspension-load deposits with a coastal plain flora (paleoecological group F), palynofacies indicating high water tables that are more common in lower fluvial to coastal plain deposits (palynofacies groups B. C, and D), and lithofacies that suggest coastal plain deposits (abundant burrow trails, lenticular lamination)

Based on these two surfaces and the parasequence stacking pattern (see Fig. 6-16), two sequences and 3 systems tracts were recognized. For the first sequence, R.1, only the upper part of the HST was studied, the upper Cuervos Formation. The second sequence, R.2, also was partially studied, and it is composed of a LST, meters 0 to 285.5, Mirador Formation, and a TST which only the lowermost part, 285.5-307.5m, was studied (lower Carbonera Formation, meters 0 to 20.5).

Uribe section. Two important surfaces were identified in this section (Fig. 6-17). The first surface is identified as a MFS at 0 meters, Lisama-La Paz contact. It is characterized by an abrupt facies change from suspension-load deposits of the upper coastal plain below the surface to braided channels of bed-load deposits in the fluvial plain above the surface. This abrupt facies change indicates a sequence boundary (Van Wagoner *et al.*, 1990). The next important surface is at 1046m, La Paz-Esmeraldas contact, and it is recognized as a TS. It is characterized by a fast facies change from mixed-load (lenticular amalgamated quartzarenites) to suspension-load deposits (light-

gray claystones). Unfortunately, palynofacies and palynomorph paleoecological data above and below this interval are lacking because all analyzed samples were devoid of palynomorphs and dispersed organic matter precluding a confirmation of this interpretation.

Based on these two surfaces and the parasequence stacking pattern (see Fig. 6-17), two sequences and 3 systems tracts were recognized. For the first sequence, U.1, only the upper part of the HST was studied, the upper Lisama Formation. The second sequence, U.2, also was partially studied, and it is composed of a LST, meters 0 to 1046, Lisama Formation, and a TST which only the lowermost part, 1046-1066 5m, was studied (lower Esmeraldas Formation, meters 0 to 20).

Discussion

The basin geometries during the Paleocene in Colombia are very complex and they do not seem to fit a single model (Bayona and Jaramillo, 1998). From the literature, it is evident that the northern part of the Middle Magdalena area (area of Uribe section) behaved as a foreland basin during the Paleogene (Porta, 1974; Pava, 1984; Cooper *et al.*, 1995; Gomez, 1998). The area of Catatumbo (Regadera section) was not connected with the northern Middle Magdalena because the Santander massif was already uplifted (Etayo-Serna *et al.*, 1983; Fabre, 1983), and it seems to be related to the Maracaibo Basin to the northeast. Geology in the Colombian Llanos foothills is very complex as Guaicaramo fault system has had significant horizontal W-E shortening (~100km according to Dengo and Covey, 1993) as well as N-S displacement (Montes, personal communication). All data suggest that sediment source was mainly the craton (Vergara and Rodriguez, 1996), although tectonic subsidence could be related to the foreland formed east of Central Cordillera at the beginning of the Tertiary (Cooper *et al.*, 1995). This suggests that stratal geometry of the Llanos/Llanos foothills does not have a physical connection with the Middle Magdalena facies and it acted as a passive margin as

sediments were derived from the craton and subsidence increased basinward. Given these considerations, the sequence stratigraphic hypothesis for each section will be discussed separately as probably they were not part of the same depositional system and were subject to different relative sea level histories.

Uribe area (foreland in Northern Middle Magdalena area). Sequence stratigraphy in a foreland basin is fundamentally different from passive margins where models originally developed. While in passive margins the subsidence rate increases away from land, in foreland basin it decreases. Subsidence in foreland basins is mainly due to flexural isostatic compensation of the lithosphere in response to tectonic loading in a convergent orogeny (Johnson and Beaumont, 1995). During a thrust event, subsidences of the foreland and back bulge basins increase while forebulge is uplifted (Fig. 6-20). This produces an increase of accommodation space in foreland and backbulge basins and a decrease in forebulge basin. Through time, the thrust load migrated cratonward producing a migration of axis of maximum subsidence cratonward (Giles and Dickinson, 1995).

These unique characteristics of foreland basins result in different stratal patterns from those predicted in classic sequence stratigraphic models. However, the basic principles of sequence stratigraphy still can be applied (Posamentier and Allen, 1993). In foreland basins there are two tectonostratigraphic zones, A and B. In zone A the subsidence rate is higher that maximum eustatic fall, while in zone B it is lower than maximum eustatic fall. Depending on the location of the shoreline (zone A and B) the stratal architecture would be different (Fig. 6-21). A type 2 sequence boundary would developed if the shoreline is in zone A during a eustatic fall (Posamentier and Allen, 1993). A type 1 sequence boundary would developed if shoreline is in zone B during a eustatic sea level fall (Fig. 6-21, Posamentier and Allen, 1993).

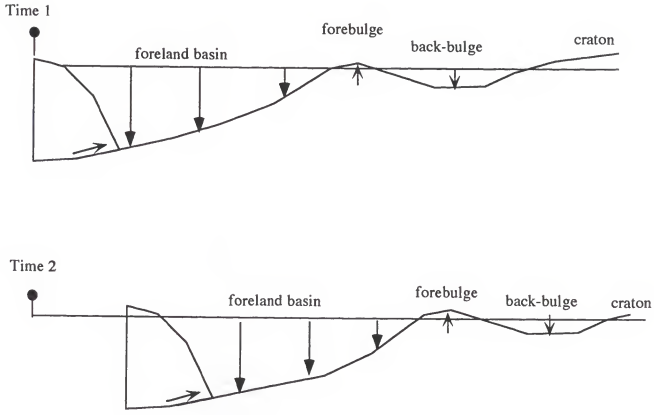


Figure 6-20. Relationship of lithospheric flexure to accomodation space in foreland systems. In time thrust load increase subsidence in foreland and backbulge and uplift forebulge. In time 2, thrust load advance cratonward, and depocenters migrate as well (after Giles and Dickinson, 1995)

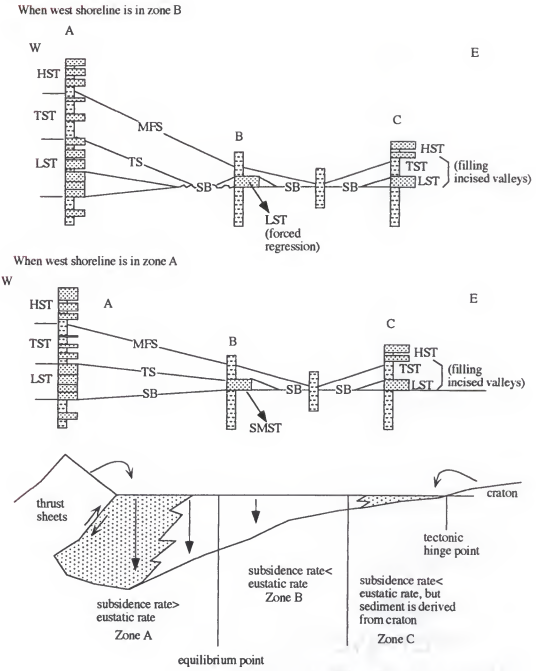


Figure 6-21. Sequence stratigraphy and subsidence profile across foreland basins. SMST: shelf-margin systems tract LST: lowstand systems tract (modified from Posamentier and Allen, 1993, and Cooper *et al.*, 1995)

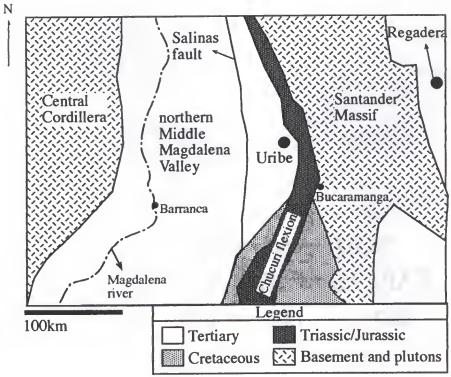
The stratal patterns of the section in Uribe indicate that this was accumulated in zone A (see Fig. 6-21) as fluvial sedimentation occurred at different rates, resulting in channel clustering when accommodation space decreased, but always within fluvial zone as predicted for this zone of the foreland (Posamentier and Allen, 1993). The Uribe sequence stratigraphy suggest an abrupt change in accommodation space and/or advance of thrust front, that produced the sequence boundary at the base of U.1 (base La Paz Formation, Fig. 6-17). Fluvial arenite facies of La Paz lowstand systems tract (LST) indicate a net decrease in generation of accommodation space in relation to the highstand systems tract (HST) of Lisama Formation and transgressive systems tract (TST) of Esmeraldas Formation. This decrease in accommodation space could be due to an eustatic sea level fall (Posamentier and Allen, 1993) or a decrease in flexural loading (Giles and Dickinson, 1995). However, no evidences of an incised valley was found, and only a channel amalgamation was produced. An alternative hypothesis implies the advance of the thrust front during this interval that resulted in a net facies progradation (fluvial prograding over coastal deposits). Also, a change in weathering and erosion rates product of climatic change can lead to facies change. The analysis of additional sections in this basin is necessary to confirm any of these hypotheses.

This sequence boundary at the base of la Paz is recognized over all the basin, although for some authors it is encompassing a large amount of time, including early and middle Eocene times (Dengo and Covey 1993, Cooper *et al.* 1995; Ramon and Cross, 1997; Suarez 1997a, b; Villamil and Restrepo, 1998). This time-gap does not seem to be supported by the palynostratigraphy of the Uribe section (Fig. 5-12), although samples immediately above and below the sequence boundary (SB) were sterile. Sedimentation of La Paz took place in synclines while erosion developed in anticlines (Julivert, 1961; Fabre, 1983). This large time-gap, therefore, is probably not regional and only restricted to anticlinal areas because in synclinal areas (as in the Uribe section) this time-gap is not recognized (Julivert, 1961). Probably the time-gap, where present, started during the

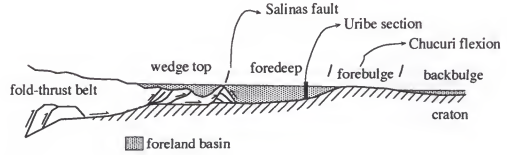
accumulation of the Lisama (Paleocene), as in many areas west of the Salinas fault, Lisama is absent from anticline axis, and it is in angular unconformity above Cretaceous sediments in anticline flanks (Julivert, 1961).

The situation during the uppermost Paleocene and lower to middle Eocene in the Uribe area could be similar to the zonation of the modern foreland basin adjacent to the central Andes described by Horton and DeCelles (1997) (Fig. 6-22). There, the foreland is divided into 4 zones: wedge-top, foredeep, forebulge, and backbulge (Horton and DeCelles, 1997). The wedge top would constitute the middle Magdalena Valley west of the Salinas fault; in this area stratum accumulate on top of actively growing structures of the orogenic wedge, containing thrust-fault and associated folding of the orogenic wedge. The foredeep would constitute the area east of Salinas fault where Uribe section is located. In this zone the accumulation is thick and continuous. The forebulge would be the Chucurí flexure where La Paz is absent, that is a structural high where erosion or nondeposition is predominant. The backbulge does not seem to have an analog in the Eocene. It is unclear if this foreland zonation would apply to the southern part of the middle Magdalena area for the same time interval, and seems to be more complicated, with several subbasins in a broken composite foreland basin and probably isolated from Llanos foothills and Llanos areas (Gomez, 1998).

Piñalerita area (craton-derived sediments, passive-like margin). The sequence stratigraphic model for the Piñalerita agrees for the most part with that proposed by Cooper *et al.* (1995) and Cazier *et al.* (1995) for the Cusiana area, and the Guerrero and Sarmiento (1996) for the Guadualera area and Vergara and Rodriguez (1997) for the Caño Blanco-Playonera area (Fig. 6-19). However, these "robust" correlations are lost when ages of depositional sequences are compared (Fig. 6-23). Can these sequences be correlated, are age determination incorrect (misidentifications), or are different authors using different criteria for assigning ages? Answers to these questions are difficult to



A



B

Figure 6-22 . Middle Magdalena Basin. A. Map of major tectonic elements and stratigraphic units. B. Location of Uribe section in a schematic cross section of northern Middle Magdalena Valley foreland basin system during the Eocene (after Horton and DeCelles, 1997).

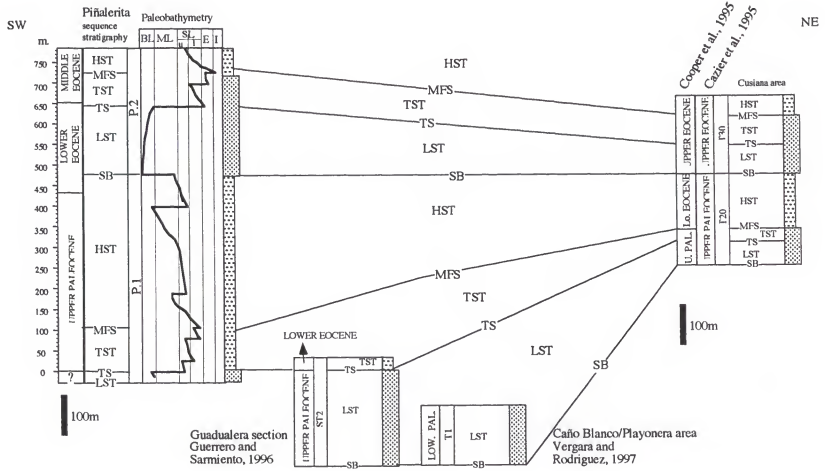


Figure 6-23. Sequence stratigraphy interpretation for the Llanos foothills, Colombia. HST=highstand systems tract, LST=lowstand systems tract, TST=Transgressive systems tract, SB=sequence boundary, TS=transgressive surface, MFS=maximum flooding surface. Paleobathymetric key in Figure 6-15, location of sections in Figure 6-24

evaluate, especially with Cooper *et al.* (1995) and Cazier *et al.* (1995) works, because they did not provide data supporting age determination. It is striking, however, that "Cuervos" age by Cooper *et al.* (1995, Fig.4 and text) is late Paleocene while it is early Eocene for Cazier *et al.* (1995, text) and for Cooper *et al.* (1995, Fig. 6) (see Fig. 6-19). Guerrero and Sarmiento (1996) provided palynological range chart used for dating the Paleocene sequence. Their data only contains one sample comparable with Piñalerita (in their lower part of Socha Superior, see Fig. 6-19). This sample has first appearance datum (FAD) of *Foveotricolpites perforatus* which occurs at 81m, in the lower part of Arcillas de El Limbo in the Piñalerita section (Fig. 5-12). Therefore, these two units are isochronous. However, Guerrero and Sarmiento (1996) consider this sample as lower Eocene (Ypresian) without further comment. This interpretation is not supported by graphic correlation performed in this study that resulted in FAD of *Foveotricolpites perforatus* to be within late Paleocene.

Assuming that key surfaces (sequence boundaries, transgressive surfaces, and maximum flooding surfaces) are part to the same depositional sequence, it could be argued that they correspond to chronostratigraphic surfaces and could be used for correlation purposes (Van Wagoner *et al.*, 1990). Then, the sequence P1 of Piñalerita section (Areniscas de El Morro-Arcillas de El Limbo) would correspond to T1 (Vergara and Rodriguez, 1997), ST2 (Guerrero and Sarmiento, 1996), and T20 (Cooper *et al.*, 1995) sequences (Figs. 6-23, 6-24). However, there is a difference. Is the transgressive surface (TS) at the middle Barco Formation in Cooper *et al.* (1995) scheme correlated with the TS at top of the Areniscas de El Morro in Piñalerita and at the top of the Socha Inferior in Guerrero and Sarmiento (1996)? Without proper dating it is impossible to test this hypothesis (Fig. 6-23). A second possibility is that the transgressive surface (TS) at the middle of Barco corresponds to a TS in the upper Arenisca de El Morro that was not recognized in this study. In the Piñalerita section only the last 3 meters of this formation were studied and palynological samples were almost sterile. In a nearby section (10km

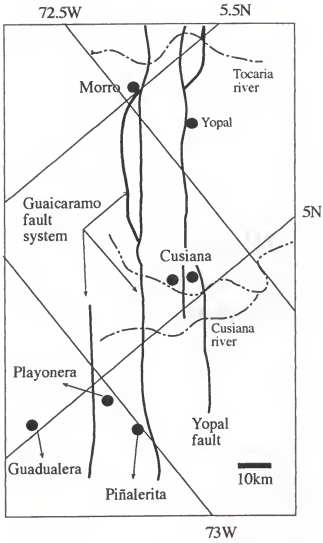


Figure 6-24. Simplified map of the Llanos foothills showing major structural features and sections referred to in this study (After Cooper *et al.*, 1995).

northwest), Vergara and Rodriguez (1997) found evidenced of marine influence (bidirectional cross-bedding) in the upper Socha Inferior. On the other hand, Guerrero and Sarmiento (1996) did not find evidence of marine influence in the Socha inferior Formation in a section 30km west of La Piñalerita.

The topology of the sequence P.2 in Piñalerita is very similar to T30 to lower T40 in Cusiana area (Cooper *et al.* 1995; Cazier *et al.*, 1995). A lowstand systems tract (LST) in lower Areniscas de El Limbo (or "Mirador" in Cooper *et al.*, 1995), a transgressive systems tract (TST) in upper Areniscas de El Limbo and lowermost San Fernando (Cooper *et al.*, 1995 considered the TST to include only the upper part of "Mirador"), and a highstand systems tract (HST) in the lower San Fernando (Cooper *et al.*, 1995 included all of "Carbonera"). The TS at the upper Areniscas de El Limbo in Piñalerita is well supported by palynology (dinoflagellate cysts, coastal plain pollen), and lithology (*Thalassinoides*). The maximum flooding surface (MFS) at lowermost San Fernando is also well supported by a high abundance and diversity (more than 10 species) of dinoflagellate cysts, palynofacies (group 5) in sample 725m, and the parasequence pattern, regressive estuarine muds prograding over transgressive tidal-estuarine muddy sands or estuary-mouth sands, as observed in Gironde estuary, France (Allen and Posamentier, 1993). Samples above and below, although of similar muddy facies, decrease in abundance and diversity of dinocyst indicating less marine influence.

The topology of this P.2 sequence is very similar to that modeled by Zaitlin *et al.* (1994) (Fig. 6-25) and observed by Allen and Posamentier (1993) in Quaternary incised valley fillings in the Gronde estuary, France. There, the fluvial valley incised during the last sea-level fall is being filled. The sequence comprises a LST of fluvial gravel and coarse sands, a TST that comprises the bulk of the incised valley and forms a landward-thinning wedge of tidal-estuarine sands and muds, that in the estuary mouth are overlain by a thick, coarse-grained tidal-delta and estuary-mouth tidal-inlet sands. The HST forms a prograding, tide-dominated estuarine bayhead delta that is still filling the valley. In the

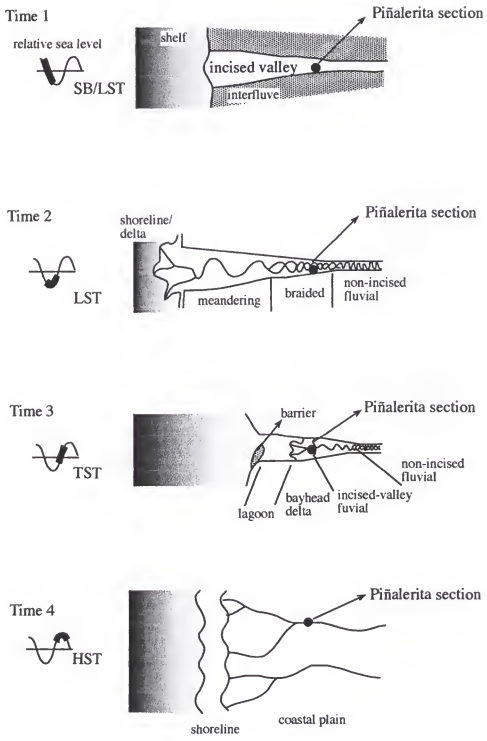


Figure 6-25. Schematic location of Piñalerita section in a plan view of a simple incised-valley filling during a relative sea level fall and rise cycle (times 1to 4). SB: sequence boundary, LST:lowstand systems tract, TST:trangressive systems tract; HST:highstand sytems tract (adapted from Zaitlin *et al.*, 1994)

interfluves, the sequence boundary is expressed as a wave ravinement surface with TST and HST unconformably overlying Pleistocene or Tertiary substrates.

The whole sequences (P.1 and P.2) seems to be prograding in a northeast direction as thickness increases toward south (Figs. 6-23, 6-24), and paleocurrents and petrofacies (Vergara and Rodriguez, 1996) indicate that sediment source was the craton during the accumulation of lower P.1.

Regadera area (Santander and Craton-derived sediments). The Regadera area was in a different basin (Catatumbo area) separated from Middle Magdalena Basin by the Santander Massif that was already uplifted by the Paleocene (Fabre, 1983; Etayo *et al.*, 1983; Cooper *et al.*, 1995). An abrupt decrease in accommodation space is marked by the sequence boundary of R.2 Sequence. The Mirador LST is capped by a flooding surface that appears to have regional significance (Fig. 6-26). No evidence of an incised valley was found. Eocene sediments of the Maracaibo Basin probably were derived from the Santander Massif and the craton and systems prograded toward the Maracaibo Gulf (Fabre, 1983; Colmenares and Terán, 1993). There are no sequence stratigraphic studies of the area, and very few published sections in the area present paleontological data of any kind. Only one section (Gonzalez, 1967) presents a pollen range chart. Another paper presents some general palynological data but the distribution of taxa is not showed (Colmenares and Terán, 1993). In general sediments in Catatumbo area seem to be prograding toward the Maracaibo Gulf, and sediment sources were the Santander Massif and the Mérida arch (Colmenares and Terán, 1993). This basin probably was isolated from both Middle Magdalena (Uribe) and Llanos foothills (Piñalerita) during the Paleocene-Eocene, as consequently their stratal architectures do not seem to correlate.

Overall Sequence Stratigraphy. The three sections seem to be located in three separate basins (Llanos-western Eastern Cordillera; Middle Magdalena Valley; and

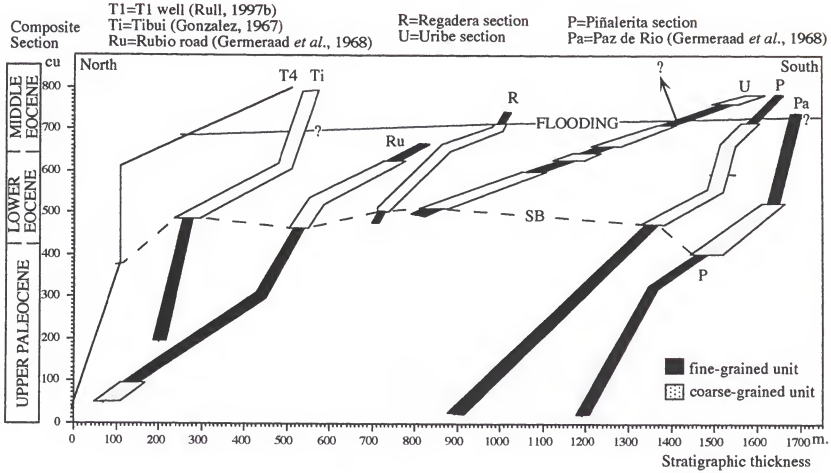


Figure 6-26. Regional correlation of all available sections with palynological information for the late Paleocene-Eocene interval in Colombia and western Venezuela

Catatumbo-Maracaibo areas). During the late Paleocene-Eocene, each basin probably had a different subsidence, sediment source, and sediment accumulation history. Therefore, stratigraphic sequences proposed in each section should be particular to each basin. However, two stratigraphic horizons could be identified in all three basins (Fig. 6-26), suggesting that they were formed in response to large-scale tectonic and/or eustatic events. The first one is the sequence boundary during the Lowest Eocene. The second is the regional flooding during the middle Eocene. This flooding was seen in Piñalerita (Foothills), Regadera (Catatumbo), and T1 Well (Maracaibo). In Uribe section, this flooding seems to correspond to a parasequence boundary (meter 575). Environmental information that could confirm this flooding in the Tibui, Paz de Rio, and Rubio Road sections is lacking

Finally, chronostratigraphic correlations based either on formational names or lithology are very suspect. The comparison of diverse localities indicate that very often a formational boundary or lithological change does not correspond to a time line (Fig. 6-27), especially in areas like Colombian Paleogene with several small basins with different subsidence and sedimentation histories. However, Colombian geological literature is filled with chronostratigraphic correlations of this sort (Porta, 1974). It is evident that extensive paleontological studies are very necessary for an adequate understanding of the history of this region.

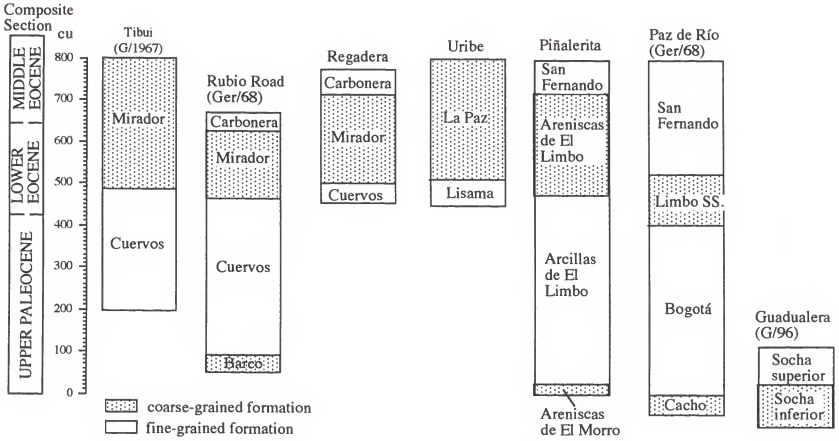


Figure 6-27. Lithostratigraphy of all available sections with palynological information for the late Paleocene-Eocene interval in Colombia and western Venezuela. G/67=Gonzalez, 1967; Ger/68=Germeraad *et al.*, 1968; G/96=Guerrero and Sarmiento, 1996)

CHAPTER 7
DIVERSITY

The late Paleocene-early Eocene interval is characterized by a long period of global warming that culminated in the Eocene Thermal Maximum, the highest ocean temperature of the last 65 million years. The warming has two distinct peaks, at the Paleocene-Eocene boundary and in the middle to late early Eocene (Wing *et al.*, 1995).

The warming at the Paleocene-Eocene boundary, or late Paleocene Thermal Maximum (LPTM, Zachos *et al.*, 1993) is recognized by a rapid world-wide warming of high to mid-latitude surface waters, change in ocean circulation, and deep-water oxygen deficiency (Miller *et al.*, 1987; Kennett and Stott, 1991; Pak and Miller, 1992; Zachos *et al.*, 1993; Bralower *et al.*, 1997); this event also has been detected in the Caribbean (Bralower *et al.*, 1997). The LPTM correlates with a 35% decrease in plant diversity in mid-latitudes of North America (Wing *et al.*, 1995; Wing, 1998), and a dramatic mammalian turnover (Clyde and Gingerich, 1998) in North America and Europe. Tropical planktonic foraminifera diversified during this time (Kelly *et al.*, 1998), while deep-sea benthic foraminifera suffered a major extinction (Pak and Miller, 1992). The LPTM is associated with a large and abrupt negative excursion of stable carbon isotope of marine and terrestrial materials (Koch *et al.*, 1992; Kennett and Stott, 1991). This spike could be due to dissociation of methane hydrates because of the fast warming of deep waters (Dickens *et al.*, 1995), although this hypothesis is still highly controversial (Bralower *et al.*, 1998; Dickens, 1998)

The late early Eocene (or Eocene Thermal Maximum) is recognized as having the highest temperature in the last 65 million years (Wolfe, 1978; Wolfe and Poore, 1982; Miller *et al.*, 1987; Prentice and Matthews, 1988) greatly affecting the vegetation in both

southern and northern middles to high latitudes where an important increase in plant diversity has been documented (Askin and Spicer, 1995; Christophel, 1995; Wing *et al.*, 1995; Wing, 1998).

Competing models exist for explaining the early Eocene warming. Increases in both greenhouse gases and oceanic heat transport have been proposed to explain the nature of this warm climate (Rind and Chandler, 1991; Pak and Miller, 1992; Sloan and Barron, 1992; Sloan *et al.*, 1995). When levels of atmospheric CO_2 similar to preindustrial values are used, a slight cooling in terrestrial tropical environments especially for South America is produced (Sloan and Rea, 1995; Sloan and Morrill, 1998). On the contrary, when CO_2 levels six times higher are used (greenhouse model), land temperature in tropics rises by 4 degrees Celsius and soil moisture decreases (Sloan and Rea, 1995). Precipitation over equatorial land does not change in either scenario of CO_2 concentrations (Sloan and Rea, 1995). Data from oxygen isotope values of planktonic and benthic foraminifera for the late Paleocene to early middle Eocene indicate that tropical sea surface temperature did not change during this time interval, with values similar to the Holocene (Zachos *et al.*, 1994), although, the datapoints analyzed from tropical regions were very few (one site for the late Paleocene, two sites for the early Eocene, and no sites for the early middle Eocene).

No data from terrestrial tropical regions are available to test these models and further contribute to our understanding of these examples of global warming. Changes in tropical vegetation would be expected if climate was also drastically modified in tropical areas during this time. An abrupt departure from previous environmental conditions, well beyond the normal ability of plants to adapt, can produce extinctions, rapid immigration-emigration, and ecological replacement (Niklas, 1997).

High annual rainfall and/or little dry-season stress are correlated to a high number of plant species in lowland neotropical forests (Gentry, 1981; 1988), therefore, in a greenhouse scenario, a decrease in plant diversity could be expected as effective

precipitation and soil moisture decrease, and water-stress increases. On the other hand, an increase in plant diversity would occur in a slightly cooler tropical region as effective precipitation and soil moisture increases. Thus, analysis of plant diversity, seen through the pollen and spores record, could provide data to assess the validity of climatic models for the late Paleocene-middle Eocene warming interval.

Previous Studies

Studies addressing plant diversity in the Paleocene-Eocene of the tropics have not been published. Most of palynological studies have focused in biostratigraphy, that tends to use a small part of the total pollen/spores flora found in a sample. However, several authors have suggested that Eocene floras seem to be more diverse than during the preceding Paleocene. Van Hoeken-Klinkenberg (1966) in the Eocene of Nigeria found an increase in morphological variety of species and especially the presence of abundant small triporate and brevicolpate grains. Gonzalez (1967) in Catatumbo area noted an explosive development of angiosperms at the Paleocene/Eocene boundary with more than 20 new species arising and angiosperms becoming dominant. Colmenares and Terán (1993) also reported a high pollen diversity at the early Eocene (Mirador Formation) in southwestern Venezuela and subsequently decreasing in the Carbonera Formation (middle Eocene-Oligocene).

Analysis of diversity based on pollen and spores must be done very carefully, as several taphonomic and sampling artifacts can affect the diversity of a sample. In fluvial environments, for example, channel-fill and crevasse-splay environments tend to have more species because they are more open to transported palynomorphs and changing physical environmental conditions (Potter, 1976; Farley, 1990). In the delta of the Orinoco river transport of pollen is restricted, and pollen of the local swamp forest is dominant in the sediments, while offshore the pollen is better mixed (Muller, 1959). There is a trend toward higher diversity values (Simpson index) from fluvial to deltaic

environments (Nichols and Traverse, 1971). Also, a systems tract can exert a control on the pattern of number of species observed (Holland, 1995). However, in spite of these multiple problems, the pollen and spores record is the most reliable record of plant diversity in tropical regions. Fortunately, there are a number of statistical analyses (see Chapter 3) that can be applied to the raw diversity data to account for the many factors that can exert an effect on temporal and spatial patterns of diversity.

Results

An analysis of pollen and spores diversity was only performed for the Piñalerita section. The other two sections were not included because the sampling recovery was not adequate for this type of analysis and only the Eocene was studied. In the Piñalerita, on the other hand, the palynomorph recovery was good, sampling was more intense, and both Paleocene and Eocene strata were analyzed. Also, as the comparison Paleocene-Eocene is done in same section, the differential preservation due to diverse weathering rates can be minimized. Both Paleocene and Eocene strata were sampled along the same creek, in similar mountain slopes, and separated from each other for about 100-200 meters in horizontal scale. Therefore, a similar weathering rate could be expected in samples taken from either Paleocene or Eocene strata, and differential pollen preservation due to recent weathering would not be expected.

Comparisons of the floral assemblages through the entire section was done using detrended correspondence analysis (DCA) as shown in Figure 7-1a. This analysis was performed on range-through presence-absence dataset of the range chart for the Piñalerita section. Axis 1 values (that explain 22% of variation) in Paleocene strata (5.4 to 311 meters) ranges from 0 to 1.29 while values in Eocene strata (475 and above meters) fluctuates between 1.8 to 4.

Simpson index (SI, expressed as -loge(SI)) for Paleocene samples have a mean of 2.09 (standard deviation SD=0.46), while Eocene samples have a mean of 2.53

(SD=0.60) (Fig. 7-1b). The isolated earliest Eocene sample (475m) has an index of 0.71 and was not included in calculation of Eocene index mean. SI means also were calculated for samples arranged according their position in systems tracts: Paleocene transgressive systems tract (TST)= 1.90 (SD= 0.38), Paleocene highstand systems tract (HST)= 2.28 (SD= 0.45), Eocene TST= 2.47 (SD= 0.75), Eocene HST= 2.58 (SD= 0.39).

Rarefaction curves produced by the rarefaction calculator (see Methods) are shown in Figure 7-2. Each curve represents the hypothetical relationship between sample size (number of pollen/spores counted per sample) versus number of species found. This allows a comparison of diversities from samples of different sizes. The rarefaction curves also were separated according to the position of the samples in a systems tract. Thus, Paleocene and Eocene transgressive systems tract (TST) were compared with each other, as well as Paleocene and Eocene highstand systems tract (HST) (Figs. 7-3, 7-4).

Using rarefaction results, number of species were calculated for each sample at a counting of 115 grains (samples with less than 115 grains were excluded from analysis). Bootstrapping of this dataset, using 4999 iterations, indicated a species number mean of 31.71 (confidence interval 28.69-34.70) for Eocene samples and a mean of 21.71 (confidence interval 18.31-25.01) for Paleocene samples. Mean species numbers do not overlap at 95% confidence interval (P randomization=0.00080).

Standing diversity was calculated for each sample throughout the entire stratigraphic interval using the range-through method (Fig. 7-5a). The completeness index (Maas *et al.*, 1995; CI=100*N/Nt, N=number of taxa collected in sample, Nt=total number of taxa including those inferred from range-through method) indicates a mean of 46.3 (SD=25) for Paleocene samples and a mean of 52.5 (SD=20) for Eocene samples (Fig. 7-5a). Rates of taxon first and last appearances were calculated for each sample (Fig. 7-5b). This rate indicated the proportion of first appearance datums (FAD) and last appearance datums (LAD) per standing diversity at each analyzed sample. A background

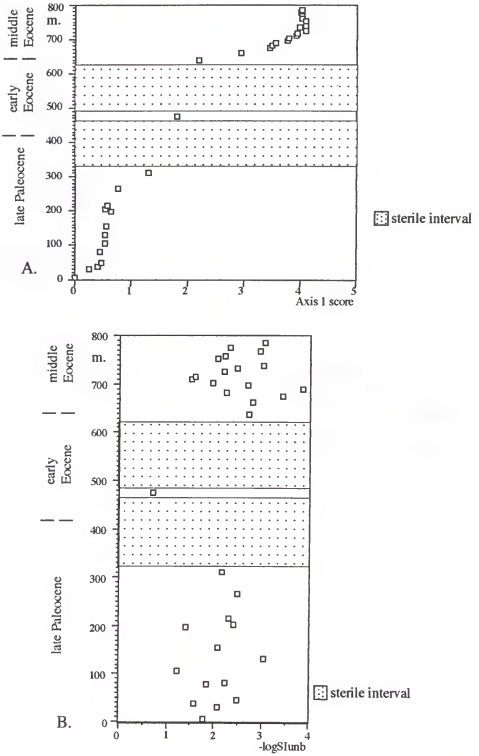


Figure 7-1. Diversity analyses A. Detrended Correspondence Analysis (DCA) of the samples based upon taxa present, axis 1 scores plotted against stratigraphic meters of each sample in Piñalerita section. Axis 1 accounts for 22% of variance. B. -loge(Simpson index) plotted against stratigraphic meters in Piñalerita section

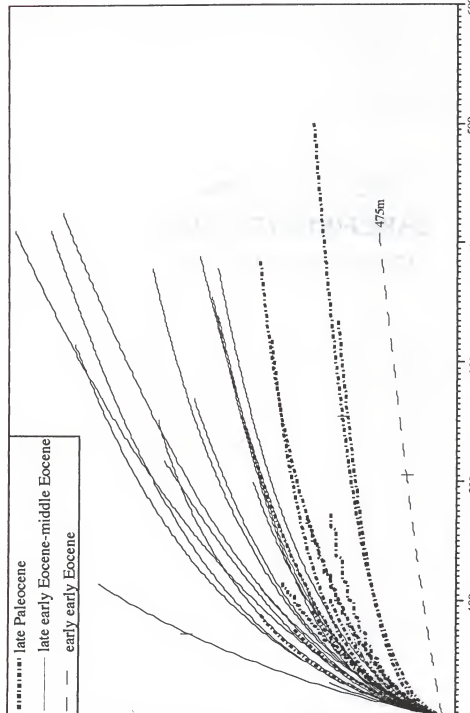


Figure 7-2. Rarefaction curves for Piñalerita samples (only sporomorphs were included). Most of late early Eocene-middle Eocene samples are characterized by higher diversities for given sample size than late Paleocene or early early Eocene samples. Vertical bar=95% confidence interval, in most cases < 2

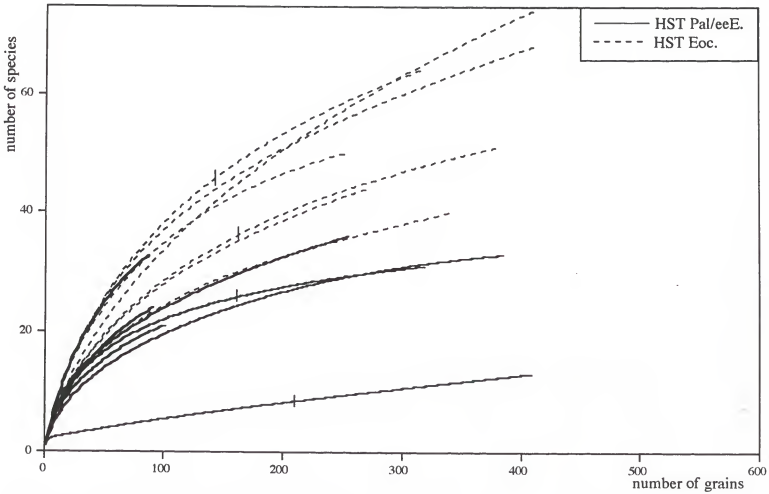


Figure 7-3. Rarefaction curves for highstand systems tract samples from Piñalerita (only sporomorphs were included). late early Eocene-middle Eocene HST samples are characterized by higher diversities for given sample size than late Paleocene/earliest Eocene HST samples. Vertical bar=95% confidence interval, in most cases < 2

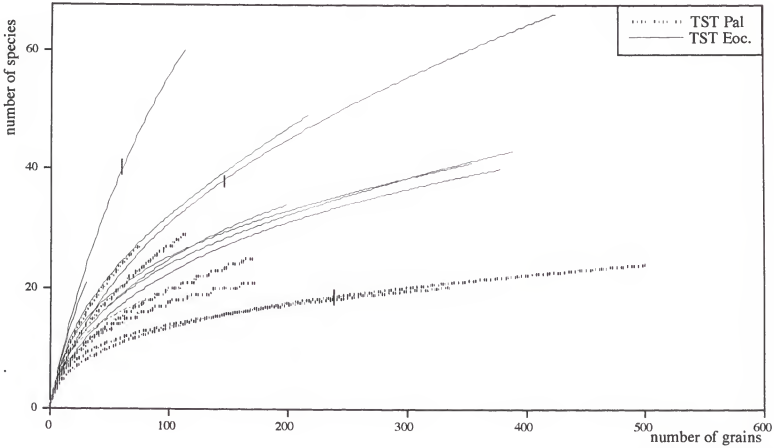


Figure 7-4. Rarefaction curves for transgressive systems tract samples from Piñalerita (only sporomorphs were included). late early Eocene-middle Eocene TST samples are generally characterized by higher diversities for given sample size than late Paleocene/earliest Eocene TST samples. Vertical bar=95% confidence interval, in most cases < 2

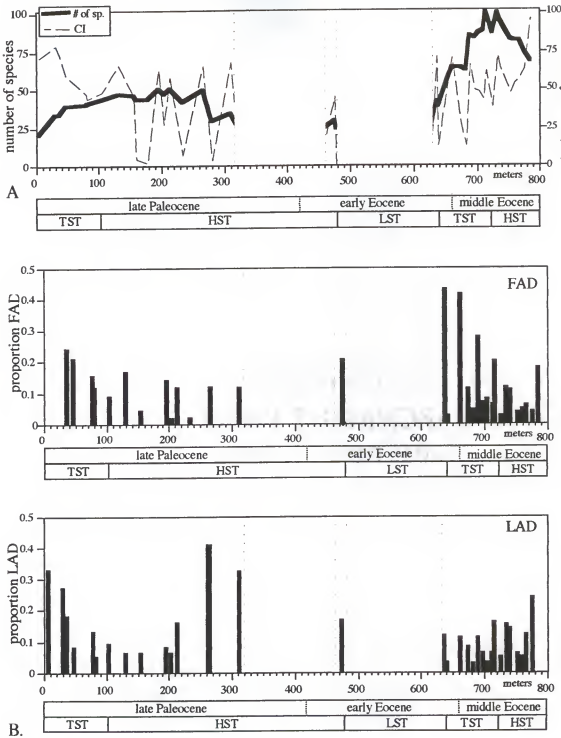


Figure 7-5. Diversity analyses. A. Standing diversity of range-through sporomorphs for the late Paleocene-Eocene interval calculated per stratigraphic meter. B. Taxon rates of FAD and LAD for same interval. White box indicates sterile interval. LST:lowstand systems tract, TST:transgressive systems tract, HST:highstand systems tract

FAD rate of 0.05-0.12 is observed for both Paleocene and Eocene samples. Background LAD rates also fluctuate between 0.07 to 0.12.

Taxa with single occurrences do not add much stratigraphic information or temporal change to the diversity analysis (Wing, 1998) but such taxa could introduce some noise to the general diversity pattern. Therefore, the standing diversity was calculated again without considering taxa with single occurrences (Fig. 7-6a). The general diversity pattern is still very similar to that observed with the whole assemblage. Taxon rates of FAD and LAD also were recalculated considering only taxa with multiple occurrences (Fig. 7-6b). Background rates of FAD and LAD are also similar to each other but lower than rates using whole assemblage, varying from 0.03-0.10 for FAD, and 0.03 to 0.08 for LAD in both Paleocene and Eocene samples. Three FAD rates higher than background were identified at 130m, 690m, and 785m (see ovals in Fig. 7-6b). Two FAD levels higher than background were identified at 35 and 265m (see ovals in Fig. 7-6b). High FAD rates immediately following sterile intervals or at the beginning of the section are probably a sampling artifact. High LAD rates at the end of the section or preceding sterile intervals are also sampling artifacts.

Cumulative first appearance datums (FAD) and last appearance datums (LAD) curves were plotted in order to better appreciate the overall change of FAD and LAD rates (Fig. 7-7a). These curves were based on taxa with multiple occurrences. The same interval of faster turnover described above could also be identified. Finally, diversity curve of taxa with multiple occurrences and range-through was plotted but in this case the species were separated in three categories: those restricted to the Paleocene, those restricted to the Eocene, and those with occurrences in both Paleocene and Eocene strata (Fig. 7-7b). Species data indicate a flora of 18 species/sample (SD=4)that occurs in both Paleocene and Eocene strata, a late Paleocene flora of 21 species/sample (SD=6), and an early-middle Eocene flora of 52 species/sample (SD=20).

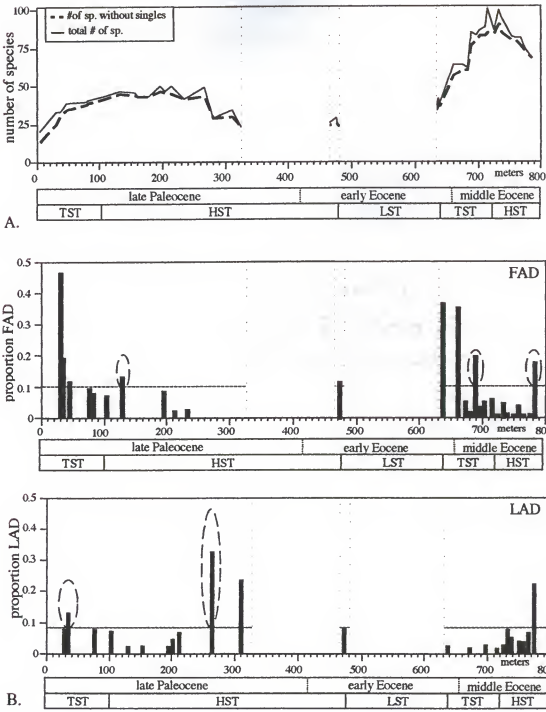


Figure 7-6. A. Standing diversity of range-through sporomorphs using whole dataset and only those taxa with occurrences in more than one sample for the late Paleocene -Eocene interval calculated per stratigraphic meter. B. Taxon rates of FAD and LAD for same interval but excluding taxa with occurrences in only one sample. White box indicates sterile interval. LST:lowstand systems tract, TST:transgressive systems tract, HST:highstand systems tract. Dash vertical line correspond to background LAD and FAD. Ellipsoids indicate significant increases in FAD and LAD rates

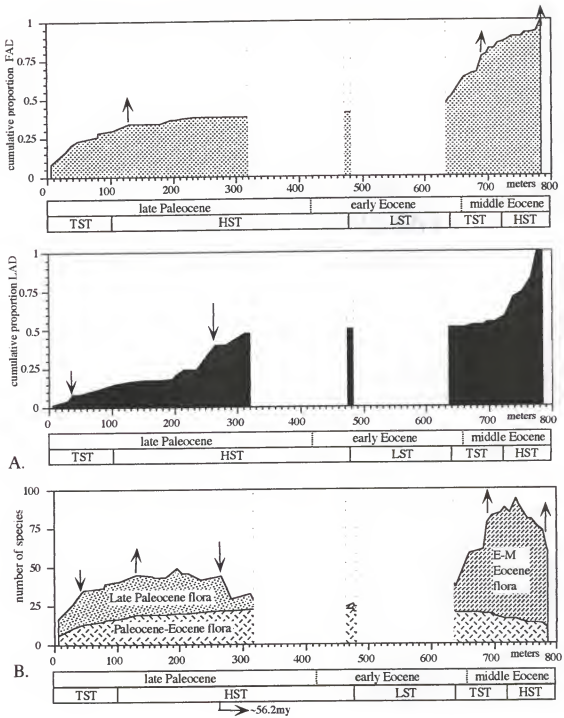


Figure 7-7. Diversity analyses. A. Cumulative proportion of taxon FAD and LAD, taxa with occurrences in only one sample are excluded. B. Standing diversity of range-through sporomorphs divided in those restricted to Paleocene, restricted to Eocene, or that occur in both Paleocene and Eocene strata. Taxa with occurrences in only one sample were excluded. White box indicates sterile interval. LST: lowstand systems tract, TST:transgressive systems tract, HST:highstand systems tract. Arrows indicate floral turnover higher than background

Palynoflora of northern South America was compared with assemblages from U.S. Gulf Coast, Central America and tropical Africa (see Chapter 3 for references used in the palynoflora comparison). Table 7-1 summarizes taxa that are shared by both northern South America and Gulf Coast, Caribbean/Central America, and tropical Africa during the Paleocene and Eocene. In Table 7-1, only taxa with first appearances within the Paleocene or Eocene are included. The percentages calculated indicate the proportion of the northern South America palynoflora that is shared with another region in a specific span of time. Eleven-point-five percent of the taxa are shared with tropical Africa during the Paleocene and 11% during the Eocene (here are included taxa appearing during the Eocene in Africa and those that were already present in Paleocene and extend into the Eocene). Zero-point-seven percent of taxa are shared with Gulf Coast in the Paleocene and a 5.25% in the Eocene. Six-point-six percent of taxa are shared in the Eocene with Caribbean and Central America (Fig. 7-8). Paleocene sediments in the Caribbean and Central America have not been studied.

Discussion

The underlying evolutionary signal of the pollen and spores record is masked by a multitude of factors that also can control their distribution as lithofacies, sample position in systems tracts, differences in sampling intensity, and sample preservation (Nichols and Traverse, 1971; Holland, 1995; Paul, 1998). Therefore, an analysis of pollen and spores diversity must take into account, in the first place, changes due to non-evolutive factors (depositional system tracts, preservation, sampling artifacts) before any inference can be made from the observed diversity pattern.

The analysis was done based on a single section, ruling out any possible difference due to differential sample preservation, that is a highly problematic factor in tropical areas where weathering rates are high. Experience has shown that samples taken in old road-cuts would generally produce sterile to low recovery palynological samples,

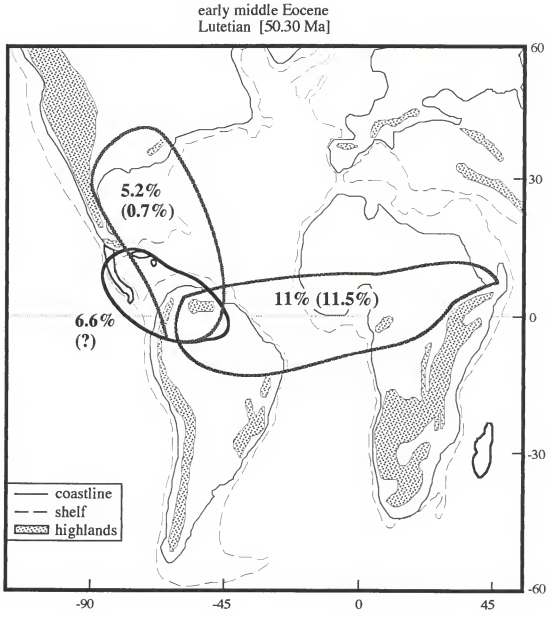


Figure 7-8. Paleogeographic map of the early middle Eocene (after Scotese, 1992). Porcentage of shared similarities between northern South America and tropical Africa, Caribbean/Central America, and the Gulf Coast are shown for each zone. Percentages in parenthesis indicate similarities during the Paleocene for same areas. Paleocene data for Caribbean and Central America are not published

Table 7-1. Sporomorph species shared by Africa, Gulf Coast, and Caribbean/ Central America with Northern South America. A=tropical Africa, GC=Gulf Coast, C=Caribbean/Central America, P=Paleocene, E=Eocene. Only are included species with first occurrences in Paleocene or Eocene

Taxa	A P	A E	GC P	GC E	C E	affinities	paleoecology	
Anacolosidites luteoides	1	1		1		Olacaceae		
Annutriporites iversenni	1							
Cricotriporites operculatus		1						
Echitriporites trianguliformis	1					Proteaceae	coastal plain	
Longapertites microfoveolatus	1					Annonaceae		
Longapertites proxapertitoides				1		Annonaceae		(*Longapertites* sp. in GC)
Longapertites vaneendenburgi	1	1				Annonaceae		
Mauritiidites franciscoi					1	Palmae		
Momipites africanus		1						
Proxapertites cursus		1		1	1	Palmae	coastal plain	(*Proxapertites* spp. in GC)
Proxapertites humbertoides	1						coastal plain	
Proxapertites operculatus	1	1				Palmae	coastal plain	
Proxapertites tertiaria		1						
Psilamonocolpites medius	1					Palmae		
Psilatricolpites minutus		1						
Racemonocolpites racematus	1	1						
Retibrevitricolpites triangulatus	1	1					coastal plain	
Retimonocolpites regio					1	Palmae	alluvial	(*Retimonocolpites* in C)
Retitricolpites americana		1						
Retitricolpites clarensis	1							
Spinizonocolpites spp.	1	1		1	1	Palmae	coastal plain	(*Nypa* in GC)
Syncolporites marginatus	1							
Syncolporites poricostatus	1	1		1				(*Myrtaceadites* sp. in GC)
Ulmoideipites krempii			1	1		Ulmaceae		
Bombacacidites annae		1				Malvaceae	alluvial	
Buttinia andreevi	1							
Gemmastephanocolpites gemmatus	1							
Retidiporites magdalenensis	1					Proteaceae	coastal plain	
Bombacacidites nacimientoensis			1	1	1	Malvaceae		
Brevitricolpites variabilis					1		coastal plain	
Cicatricosisporites dorogensis		1	1	1		Schizaeaceae	coastal plain	
Echiperiporites estelae		1			1	Malvaceae	alluvial/coastal	
Jussitriporites undulatus				1	1	Onagraceae		(*Ludwigia* in GC)
Margocolporites vanwijhei	1	1				Fabaceae		
Monoporopollenites annulatus		1		1	1	Poaceae		(*G. gramineoides* in GC)
Perfotricolpites digitatus		1				Convolvulaceae		
Perisyncolporites pokornyi		1				Malphigiaceae	coastal plain	
Psilatricolporites crassus		1			1	Pelliciераceae	coastal plain	
Psilatricolporites maculosus				1	1	Sapotaceae	alluvial	
Psilatricolporites operculatus		1			1	Euphorbiaceae		
Psilatricolporites transversalis					1	Burseraceae		(cf. *Protium* in C)
Retitricolporites irregularis		1				Euphorbiaceae		
Spironsyncolpites spiralis		1					alluvial	
Striatricolpites catatumbus	1	1		1	1	Fabaceae	alluvial	(aff. *Crudia* in GC)
Verrucatosporites usmensis		1				Polypodiaceae		
Zonocostites ramonae					1	Rhizophoraceae	coastal plain	

while samples taken at the same stratigraphic levels along creeks would produce good recovery of palynomorphs. In the Piñalerita section, all samples were taken along the same creek, and probably haven been exposed for the same amount of time under very similar conditions. The completeness index also indicates that there is no major preservational difference between the Paleocene and Eocene samples (Fig. 7-5).

A floral change trend through the late Paleocene to early-middle Eocene interval is evident from the detrended correspondence analysis (DCA, Fig. 7-1a). A similar trend has been noted in the macrofossil plant record of Wyoming Basin across the same time interval by Wing (1998). Superimposed in this trend, however, there is taphonomical and differential distribution of the plant assemblages that produced pollen and spores (DCA first axis only explains 22% of variation).

A major problem in estimating diversity is sample size. The number of species increases as does sample size (Rosenzweig, 1995). One the most important uses of "diversity" indexes is to estimate the underlying diversity in small sample sizes (Rosenzweig, 1995). These indexes allow comparisons among samples regardless of the original sample size. In this case that would mean the number of pollen grains that were counted per sample. The Simpson index (SI) indicates that there is a trend toward increasing diversity from the late Paleocene to the early middle Eocene (Fig. 7-1b). Holland (1995) found that systems tracts affect the fossil distribution in fossil assemblages. However, the pattern of increase in diversity is maintained even when samples are separated according to systems tracts (-loge(SI)=1.9 in Paleocene transgressive systems tract (TST); 2.28 Paleocene highstand systems tract (HST); 2.47 in Eocene TST; and 2.58 in Eocene HST), suggesting that the position of a sample in a systems tract does not exert a great influence on its diversity.

Lithofacies exert major influence on the distribution of fossil pollen and spores, not only by sorting taphonomically different plant assemblages but also differential preservation during the time of deposition. Thus, two samples coming from the same

stratigraphic horizon and close to each other could have different syndepositional preservation according to the position of the water-table at the moment of accumulation. This differential syndepositional preservation is directly reflected in the number of palynomorph grains counted per sample. Thus, poorly preserved samples would have relatively low palynomorph counts and therefore a low number of species. This syndepositional control is evident as shown by the wide fluctuations in the completeness index in both Paleocene and Eocene strata (Fig. 7-5a). One way to account for this difference in syndepositional preservation is rarefaction. Rarefaction analysis indicates that Eocene samples tend to have a higher diversity than Paleocene samples, regardless of the number of grains counted in each sample (Fig. 7-2). This difference is also maintained when similar systems tracts (equivalent to similar depositional environments in this particular case) are compared (Figs. 7-3, 7-4). Thus, the Eocene TST and HST are more diverse than the Paleocene TST and HST respectively, regardless of sample size. Bootstrapping also suggest that the Eocene samples have on average, a higher diversity than the Paleocene samples, regardless of the number of grains counted per sample, or the number of samples analyzed in each interval (P=0.00080).

Standing diversity (using range through-method that tends to eliminate facies and sample size effects) suggests that there is an increase in pollen/spores diversity in the late early to middle Eocene strata, from an average of 40 species (SD=8) in late Paleocene samples to 76 species (SD=17) in late early-middle Eocene samples (Fig. 7-5a). The isolated early early Eocene sample (475m) yielded a standing diversity of 29 species, fewer than most of either the Paleocene or Eocene samples. However, this sample could have a strong biofacies control (dominated by *Longapertites*), that may be producing this low value, although the possibility of a real decrease in diversity could not be fully ruled out. A similar decrease in plant diversity associated with the Paleocene-Eocene boundary has been registered by Wing (1998) in Wyoming. Analysis of standing diversity using taxa with multiple occurrences produced a similar pattern compared to that using the

whole assemblage (Fig. 7-6a). Thus, the late Paleocene is less diverse (38+/-8 species) than the late early-middle Eocene (72+/-15 species), and the early early Eocene sample has a low diversity (29 species).

Rates of floral turnover indicate three significant levels of first occurrences and two levels of last occurrences above the background rates of first and last occurrences (Fig. 7-5b, 7-6b). The pattern is better appreciated when the noise produced by single-occurrence taxa was eliminated (Fig. 7-6b). Additional first appearance datums (FAD) peaks at the beginning of the section, at the end of sterile intervals, and at flooding surfaces are sampling artifacts or product of systems tract as modeled by Holland (1995) for marine fossils in nearshore to offshore environments. Last appearance datums (LAD) peaks at the end of a section, just before the beginning of a sterile interval, and in flooding surfaces are also artifacts product of systems tracts or sampling gaps (Holland, 1995). The first important FAD peak is at 130m in the late Paleocene (Fig. 7-6b, 7-7a). It is characterized by a small increase, but above average, in rate of first appearances. The second interval is at 690m (earliest middle Eocene) characterized by a 0.1 increase in FAD proportion above the background levels. The last peak is at 785 m (middle Eocene) and is similar in magnitude to the 690 interval. This increase in middle Eocene, however, does not account for most of the standing diversity seen in this time interval. Many species probably appeared during the early Eocene stratigraphic interval that was sterile due to the predominantly clean sandstone lithofacies. These hypothetical earlier appearances were seen in graphic correlation (Fig. 5-12) and produced a high rate of first appearances in the first samples following the sterile interval (Fig. 7-6b). High rates of FAD are observed at 35m and 265m in the late Paleocene. The last one is considerably significant (0.2 above background level) and produced an important decrease in the late Paleocene flora (Fig. 7-7b) at the end of the late Paleocene, 155 m (approximately 1.7my) below the suggested position of the Paleocene-Eocene boundary defined by P5/P6 boundary (54.5my). This event could be comparable to the latest Paleocene floral

extinction observed in the Bighorn Basin by Wing (1998). The extinction occurred during the late Clarkforkian and earliest Wasatchian ages (55.7 my, slightly below the LPTM Carbon isotope excursion). This extinction extended to the later part of C24r (~54.2my). However, confirmation of this correlation is uncertain because of the poor control in time calibration of the Composite Section developed in this study (see Chapter 5). Nevertheless, the similarity of the pattern and its timing deserves further consideration.

From the overall analysis, two patterns are evident. First, there is an extinction of a late Paleocene flora, restricted to a stratigraphic interval starting 155 m (~1.7my) below Paleocene/Eocene boundary (at 420m, as defined by P5/P6 boundary at 54.5my) and lasting at most to meter 475 (~0.6my above P/E boundary) that has already evidences of an Eocene flora (Fig. 7-7b). The internal structure of this extinction is uncertain because most of this interval was either sterile or covered. Second, there is development of an early to middle Eocene flora that is approximately twice more diverse than comparable samples from the late Paleocene strata. Most of this rise in diversity should have occurred during the early Eocene, interval that was sterile and thus not observed. The topology of this increase, therefore, is still uncertain, but it could be produced by pulses as the two observed in the middle Eocene, rather than a gradual accumulation of species.

This overall pattern of plant extinction followed by increase in diversity was observed in the Bighorn Basin in Wyoming (Wing, 1998). Wing suggested that pulsed global warming (warming at the late Paleocene Thermal Maximum (LPTM) followed by cooling and then warming again at early Eocene) and intercontinental migration were the principal causes that explain the observed pattern. The similarity with the pattern found here suggests that climate in tropical terrestrial latitudes changed during the LPTM and subsequent Eocene global warming. Wing (1998) could not explain why LPTM warming produced an extinction while early Eocene warming produced a rise in diversity. Gentry (1988) found correlation between tropical lowland rainforest diversity and annual rainfall

(and/or water stress). Therefore, it is possible that diversity pattern indicates that LPTM in the Neotropics was a time of net decrease in effective rainfall. This interpretation agrees with predictions of LPTM climate models (Sloan and Thomas, 1998) of reduced July mean monthly precipitation, reduced soil moisture content, slight decrease in mean monthly surface temperature (~1C), and reduced moisture flux (net evaporation) for the tropics of northern South America.

The increase observed in plant diversity in the Neotropics during the Eocene could be related to the effects of the "Eocene Thermal Maximum" event. A net increase in effective rainfall would be expected as suggested by correlation of neotropical lowland forest diversity and rainfall today (Gentry, 1988). This interpretation would agree with early Eocene climate models that predict a slight cooling of tropics lands decreasing net evaporation and increasing effective rainfall (Sloan and Rea, 1995; Sloan and Morrill, 1998). It also would support to some extent oxygen isotope data that show cooling in tropical sea surface temperature (Shackleton and Boersma, 1981), although Zachos *et al.*, (1994) using also oxygen isotopes suggest that sea surface temperature was similar to present values. Adams *et al.* (1990), using nearest-living-relative method on paleontological evidence from larger foraminifera, mangroves, and corals, also suggest that sea surface temperature was similar to present values.

A more refined calibration of biostratigraphic framework than that developed in this study, however, is necessary to evaluate the timing of these changes in relation to oxygen isotopes (Miller *et al.*, 1987), and geologic time table (Berggren *et al.*, 1995b; Berggren and Aubry, 1998). Nevertheless, it seems that climate changed in the tropics affecting biota, which challenges views of a constant tropical climate (Adams *et al.*, 1990) where high diversity is accumulated by low extinction rates (Stebbins, 1974). Data presented here support the contrasting view of Jablonsky (1993) that the tropics are a continuous source of evolutionary novelty and not simply a refuge that accumulate diversity because of low extinction rates.

Distribution of the palynoflora in northern South America indicates that there was a low floral exchange with the Gulf Coast and Caribbean during the Paleocene and Eocene. Similar results were found by Graham (1992) who found an Eocene Caribbean-South America similarity of 2.6% (using unnamed similarity index= (a/(b+(c-a))*100, a=number of common species, b=species in Caribbean, c=species in South America). Only 6.6% of taxa are shared with Caribbean area and 5.2% with the Gulf Coast during the Eocene, and 0.7% during the Paleocene with the Gulf coast (Fig. 7-8, data from Paleocene of Caribbean is not available). A large percentage of those shared taxa (30%) have coastal plain preferences (Table 7-1), including *Spinizonocolpites* (Palmae), *Psilatricolporites crassus* (Pellicieraceae), *Proxapertites* (Palmae), and *Brevitricolpites*. Thirty-five percent of taxa shared with Caribbean region are also present in Gulf Coast, 25% are in the Gulf Coast but absent in the Caribbean, and 40% are in Caribbean and absent from Gulf Coast. This low percentage of shared taxa suggests a very limited exchange of floras between northern South America and Caribbean/Gulf Coast regions during the Paleocene-Eocene as was previously suggested by Graham (1992). Most of this change was limited to coastal plain environments. Migration seems in two opposite directions: from north to south in taxa as *Cicatricosisporites dorogensis* (Schizaeaceae), *Ulmoideipites krempii* (Ulmaceae) and *Bombacacidites nacimientoensis* (Malvaceae) which first appearances occur in the Paleocene in Gulf Coast, and in the Eocene in northern South America. South to north migration occur mostly in coastal plain elements as *Proxapertites* (Palmae), *Spinizonocolpites* (Palmae), *Brevitricolpites*, *Psilatricolporites crassus* (Pellicieraceae), and *Zonocostites ramonae* (Rhizophoraceae). Also other non-coastal plain elements migrated toward the north as *Mauritiidites* (Palmae), *Longapertites* (Palmae), *Syncolporites poricostatus* (Myrtaceae), and *Striatricolpites catatumbus* (Fabaceae). Most of this migration probably occurred during the Eocene, as all of those taxa have first appearances in the Eocene of the Gulf Coast and Caribbean while they have their first appearances during the Paleocene and early Eocene in northern South

America. This northward migration could be correlated with the Eocene Thermal Maximum that expanded tropical zones into previously subtropical areas (Sloan and Rea, 1995). Pitman *et al.* (1993) proposed possible intermittent arcuate connections between Central America and South America during the Campanian to middle Eocene interval. Data present here suggest that at least during the Paleocene this corridor did not exist, or at least was not used for floral elements to migrate south or northward. During the Eocene, however, a corridor may have existed allowing floral interchange enhanced by expanded tropical zones.

Tropical Africa and tropical South America shared 11.5% of their taxa in the Paleocene. Thirty-one percent of this flora shared are coastal plain elements such as *Proxapertites* (Palmae), *Spinizonocolpites* (Palmae), and *Retidiporites* (Proteaceae) among others (Table 7-1, Fig. 7-8). This 11.5% appeared both in Africa and South America during the Paleocene. However, the direction of migration is still uncertain due to the lack of chronostratigraphic resolution in both areas. During the Eocene the shared taxa decreased slightly to 11% (Table 7-1, Fig. 7-8). Sixty-four percent of those shared taxa appear, both in Africa and South America, during the Eocene. Thirty-three percent of them are coastal plain elements such as *P. pokornyi* (Malphigiaceae), *P. crassus* (Pellicieraceae), and *E. estelae* (Malvaceae). Others are alluvial plain elements such as *Psilatricolporites operculatus* (Euphorbiaceae), *Retitricolporites irregularis* (Euphorbiaceae), *Monoporopollenites annulatus* (Poaceae), *Momipites africanus*, *Perfotricolpites digitatus* (Convolculaceae), and *Verrucatosporites usmensis* (Polypodiaceae). These phytogeographic patterns indicate that floral interchange between eastern and western Gondwana occurring into the late Cretaceous (Coetzee, 1993), continued during the Paleogene in spite of the increasing distance of these two continents since early Cretaceous times when they started to split apart (Pitman *et al.*, 1993; ~2000km in middle Eocene, 3300km today). The importance of this continuing Paleocene-Eocene floral interchange has not been recognized by many authors (e.g.,

Coetzee, 1993; Romero, 1993). Raven and Axelrod (1974) recognized the possibility of direct migration during or before Paleocene. This Paleogene interchange has been recognized in other groups like chiclid, nandid, synbranchd, and cyprinodontiform fresh-water fishes (Lundberg, 1993), most reptile families (Bauer, 1993), and coccyzine birds (Vuilleumier and Andors, 1993). The phytogeographic patterns also indicate that latitudinal control of vegetation distribution is stronger than distances between continents, thus, while Gulf Coast/Caribbean were 1200km apart from northern South America during Eocene (Pitman *et al.*, 1993), Africa was 2000km apart from northern South America (Scotese, 1992) and still had a stronger floral interchange with South America. This lateral distribution of mainly coastal plain floras also could be further enhanced by the southern Tethys current patterns.

There is another plausible explanation for those shared taxa between tropical Africa and Neotropics during the Paleocene and Eocene. Those taxa could have speciated in subtropical areas during the late Cretaceous when the two continents were still close to each other. Then, because of the Paleocene/Eocene climatic change, they migrate into more tropical regions and consequently appeared in the tropical fossil record. However, those shared taxa have not been found in subtropical areas during the late Cretaceous. Therefore, at this time, this hypothesis has only weak support.

CHAPTER 8
CONCLUSIONS

The analysis of palynomorphs and dispersed organic matter distribution in three stratigraphic sections in the Eastern Andes of Colombia led to the following conclusions.

A biostratigraphic framework was constructed for the late Paleocene-middle Eocene interval, using the technique of graphic correlation. This framework consists of a Composite Section (CS) that has the earliest first appearance and latest last appearance datums for the most common and/or stratigraphically important taxa found in this study (Table 6-2). Correlations of the three sections analyzed and two more extracted from the literature indicate that there is not an extensive time gap encompassing the early and middle Eocene in Eastern Andes of Colombia in the sections studied (Figs. 5-11, 5-12), contrary to what several authors have previously suggested (e.g., Dengo and Covey, 1993; Cooper *et al.*, 1995). Previous palynological zonations for the area (Germeraad *et al.*, 1968, Regali *et al.*, 1974, Muller *et al.*, 1987) have serious inconsistencies and have a poor resolution for the late Paleocene-Eocene interval. On the contrary, the CS produced in this study, has a higher resolution, and constitutes a hypothesis that can be continuously tested as further information is gathered from surrounding areas. The CS was calibrated using foraminifera data and radiometric ages from tropical Africa. Unfortunately, this type of information from northern South America has not been published. Composite unit 0 of the CS is still within the late Paleocene, the Paleocene/Eocene boundary (54.5 my) was defined at composite unit 420, while the early-middle Eocene boundary (49 my) was located at composite unit 640 (Fig. 5-16). The Paleocene/Eocene boundary was defined by the P5/P6 foraminiferal boundary. Absolute ages, epoch boundaries, and foraminifera zonation followed Berggren *et al.*

(1995b), and Berggren and Aubry (1998). Calibration of this CS, however, is still poorly resolved, and there is a need for studies involving planktonic foraminifera and magnetic stratigraphy in northern South America strata during this time interval.

Interpretations of sequence stratigraphy indicate that the sections studied were located in three different basins (northern middle Magdalena, Llanos Foothills, Catatumbo) with three different subsidence histories, sediment sources, and stratal architecture. There are, however, two events that seem to have a regional distribution and probably are related to tectonics and/or eustasy. The first is an early Eocene sequence boundary (SB) that was identified in all three sections (Piñalerita, Regadera, and Uribe) and two additional sections extracted from the literature (T1 and Tibú). The second regional event is an early middle Eocene flooding that was observed in all 5 sections, although in Uribe (northern Middle Magdalena Valley) is highly interpretative (Fig. 6-26).

The Llanos foothill section (Piñalerita) was accumulated in passive-margin basin-type, where sediments were derived from the craton. It is composed by two sequences, P.1 and P.2 (Fig. 6-15). The late Paleocene to earliest Eocene P1 sequence was accumulated in mixed to suspension-load environments of fluvial to coastal plain. P1 contains a transgressive systems tract (TST) in the lower 105 m of the Arcillas de El Limbo Formation, and a highstand systems tract (HST) in the upper Arcillas de El Limbo (102-477 m). The lowstand systems tract (LST) of this sequence was not studied. The early to middle Eocene P.2 sequence was accumulated in an incised valley, that contained fluvial bed-load, fluvial suspension-load, and coastal plain to estuarine environments. P.2 is composed of a LST in the first 166 m of the Arcillas de El Limbo Formation, a TST in the upper 71.6 m of Areniscas de El Limbo and lower 10.4 m of the San Fernando Formation, and a HST beginning at 10.4 m of the lower part of San Fernando Formation. An early late Paleocene transgressive surface (TS) was identified at 0 meters (0 composite units, c.u.) based upon an abrupt lithofacies change from bed-load to

suspension-load channels. A middle late Paleocene maximum flooding surface (MFS) was identified at 105 m (105 c.u.) based upon an increase of coastal plain palynomorphs, palynofacies, bioturbation, and change from a transgressive to a regressive pattern. An early early Eocene sequence boundary (SB) was identified at 477m (477 cu) based upon an abrupt change from suspension-channels to load-channels, and a paleosoil. A late early Eocene TS is identified at 643m (596 cu) based on palynofacies, palynomorph paleoecology (dinoflagellates, coastal plain sporomorphs), and bioturbation. Finally, an early middle Eocene TST is identified at 725 m (730 cu) based on palynofacies, and paleoecology (dinoflagellates and coastal plain elements). The topology of these two sequences is similar to that proposed by Cooper *et al.* (1995) and Cazier *et al.* (1995) although dating of sequences is different.

The Regadera section (Catatumbo area) was accumulated in an area where sediments were derived from Santander massif and craton and prograded northeastward toward Maracaibo Gulf. The section is composed of two sequences, the upper part of sequence R.1 and the lower part of sequence R.2, both accumulated in fluvial environments (Fig. 6-16). R.1 is composed of a late Paleocene HST in the upper Cuervos Formation. R.2 is composed of a LST in the Mirador Formation (0 to 285.5m), and a few meters of a TST in the lower Carbonera Formation. An earliest Eocene SB (502 c.u.) was identified at 0 meters based upon an abrupt change of suspension to bed-load channels. An early middle Eocene TS is identified a 285.5 m (715 c.u.) based on palynofacies, palynomorph paleoecology (coastal plain taxa) and rapid lithofacies change.

The Uribe section (northern Middle Magdalena Valley area) was accumulated in a foreland basin with sediments derived from the Central Cordillera. The section is composed of two sequences, the upper part of sequence U.1 and the lower part of sequence U.2, both accumulated in fluvial environments (bed-load to mixed load, Fig. 6-17). U.1 is composed of a late Paleocene HST in the upper Catatumbo Formation. R.1 is composed of a LST in the La Paz Formation (0 to 1046m), and a few meters of a TST in

the lower Esmeraldas Formation. An earliest Eocene SB (510 c.u.) was identified at 0 meters based upon an abrupt change from suspension to bed-load channels. A TS is identified at 1046 meters based on a rapid lithofacies change. This TS could not be dated because of poor recovery of palynomorphs but is probably younger that the middle Eocene TS in the other two sections.

From the sequence stratigraphic analysis and biostratigraphy developed here, it is clear that the formation boundaries are not isochronous and do not match epoch boundaries as has been traditionally stated in northern South American geological literature (Fig. 6-27). Therefore, correlations attempted solely on basis of formation nomenclature or lithology are very suspect. Although, in some special cases, some formation boundaries may correspond to time lines. An example of that is the earliest Eocene SB that was found in all sections (Fig. 6-26).

Analysis of pollen and spores diversity across the late Paleocene-middle Eocene interval in the Piñalerita section indicates that the early to middle Eocene contains a statistically significant higher diversity than late Paleocene strata (Fig. 7-6a). This pattern is maintained even after sample size, number of sample/time unit, lithofacies and depositional systems, and recovery differences are accounted for. Another clear signal of the pollen record is the extinction of a late Paleocene flora at the end of the Paleocene and its subsequent replacement by a more diverse early to middle Eocene flora (Fig. 7-7b). This extinction occurred in pulses rather than gradually (Fig. 7-6b), and it is suggested that Eocene speciation was also in pulses but the lack of recovery in earliest Eocene strata interval does not allow to confirmed it. A similar extinction/speciation pattern has been found in late Paleocene-Eocene strata from Wyoming (Wing, 1998).

This palynoflora pattern could be correlated with climatic conditions during the latest Paleocene and subsequent Eocene Thermal Maximum. The late Paleocene Thermal Maximum (LPTM) produced a fast warming in neotropical areas that could be associated with the plant extinction. The Eocene warming produced slightly cooler temperatures in

the neotropics increasing water -availability that resulted in increased diversity. This suggests that tropical climates fluctuated and exerted pressure on patterns of tropical plant distribution and diversification through geological time.

Paleocene and Eocene palynofloras from northern South America had 11% and 11.5% similarities respectively with those from tropical Africa (Fig. 7-8). A third part of those shared taxa are coastal plain elements. These taxa appear during the Paleocene or Eocene, indicating that African-South America interchange still was continuing in the Eocene, and did not stop at the end of the Cretaceous or Paleocene as previous authors had suggested (Raven and Axelrod, 1974; Coetzee, 1993; Romero, 1993). An alternative hypothesis is that this shared flora is the result of a late Cretaceous stock that speciated in subtropical areas. Then, these floras migrate toward the tropics during the Paleogene warmings, and consequently appeared for first time in the tropical fossil record. This hypothesis, however, does not have support from the fossil record of subtropical areas during the late Cretaceous.

Similarities during the Eocene between northern South America and Central American/Caribbean and Gulf coast palynofloras are relatively low (6.6 and 5.2% respectively) (Fig. 7-8). Paleocene data from the Caribbean are unpublished whereas data from Gulf Coast indicate a 0.7% similarity with northern South America palynofloras. One third of those Eocene shared taxa are coastal plain elements. Migration took place in two opposite directions and was restricted to the Eocene, probably relating to the expansion of tropical zones during the Eocene warming. These two phytogeographic patterns indicate that latitudinal control on the distribution of vegetation was a stronger influence on floristic similarities than proximity of continents, as distance Africa-South America was longer than Caribbean/Gulf Coast-South America during the Paleogene.

APPENDIX A
TAXONOMIC DESCRIPTIONS

Palynomorphs (spores, pollen, and dinoflagellates) were categorized in four groups: Pteridophyte spores, Gymnosperm pollen, Angiosperm pollen, and dinoflagellate cysts. Under each category, the fossil genera are arranges in alphabetic order. All the genera treated herein are form-genera as recognized in the "Tokyo Code" (Greuter *et al.*, 1994). Wherever found necessary, new combinations are also discussed, and full synonymies given. Unnamed species are indicated informally by quotation marks. These species are not formally described because a dissertation is not considered a valid publication (Traverse, 1996). All slides are stored at the Paleobotanical collection of Florida Museum of Natural History. Coordinates are measured in Zeiss scope # 2 of the Paleobotanical laboratory of Florida Museum of Natural History. The terminology used for describing sporomorphs (pollen and spores) follows the glossary of pollen/spores terminology developed by University of Utrecht (Punt *et al.*, 1994). The terminology proposed by Evitt (1985) is used for describing dinocysts. Name of the authors and dates of valid publications that follow generic names of pollen and spores are according to Jansonius and Hills (1976, 1985, 1987). Name of the authors and dates of valid publications that follow generic names of dinoflagellate cysts follow Williams *et al.* (1998). Unless actually cited, the publications in which the names first appeared are not listed in "References" list.

PTERIDOPHYTE SPORES

Genus *Baculatisporites* Pflug & Thomson in Thomson & Pflug 1953

Baculatisporites "irregularis"

Fig. A-1, 1-3

Diagnosis: Baculatrilete, mid-sized (28um), intexine 0.7um thick, margo thin and indistinct, curvatura absent, two sizes of sculptural elements: baculae 2um high, sparsely distributed, and baculae-clavae <1um high, densely distributed, one grain found.

Specimens: PIN 75+160, 4.6 x 85.5

Discussion: *Baculatisporites* "soleus" has baculae uniform, *Clavatisporites mutisi* (Van der Hammen, 1954) *com. nov.* has a thicker intexine (1.5um), density of sculptural elements is higher, and clavae predominate (Van der Hammen, 1954).

Baculatisporites "soleus"

Fig. A-1, 4-6

Diagnosis: Baculatrilete, mid-sized (26-35um), intexine 1um thick, margo thin and indistinct, curvatura perfecta, baculae 2-3um high, 1-1.5um wide, uniform, densely distributed, density of baculae is variable.

Specimens: PIN 42+100, 5.6 x 109.7

Discussion: *Baculatisporites* "irregularis" has baculae irregularly-sized.

Genus *Camarozonosporites* Pant ex Potonie 1956, emend. Klaus 1960

Camarozonosporites "inciertus"

Fig. A-1, 7-8

Diagnosis: Trilete, mid-sized (27-30um), interradial crassitude 2um thick, proximal face laevigate, distal face rugulate, muri 1.5 um wide, groove 0.6um wide, 3-7um long, thickness of interradial crassitude is variable.

Specimens: UR 812, 13.9 X 112.1

Discussion: *Hamulatisporis caperatus* (Van Hoeken Klinkenberg, 1964) Schrank, 1994 lack interradial crassitude (Schrank, 1994)

Genus *Chomotriletes* Naumova 1939 ex 1953

Chomotriletes minor (Kedves, 1961) Pocock, 1970

Fig. A-1, 10

Diagnosis: Circular, mid-sized (29-45um), trilete mark indistinct, with concentric ridges and grooves.

Specimens: PIN 24+60, 17.9 x 86.5

Genus *Cicatricosisporites* Potonie & Gelletich 1933

Cicatricosisporites dorogensis (Potonie and Gelletich, 1933) Kedves, 1961

Fig. A-1, 11-13

Diagnosis: Cicatricosisporate, trilete, mid-sized (36-58um in proximal view), muri 1.5-2um wide, 0.5-1um high, groove 1.5um wide.

Specimens: PIN 28+0, 8.1 x 88.5

Cicatricosisporites dorogensis subsp. *minor* forv. *rugulatearis* Kedves, 1961

Fig. A-1, 14-16

Diagnosis: Cicatricosisporate, trilete, mid-sized (50-57um), rugulate to rugulate-cicatricosate, muri 2-3um wide, 0.8-1.3um high, groove 1.5-2um wide.

Specimens: PIN 28+0, 8.1 x 88.5

Cicatricosisporites "infrafoveolatus"

Fig. A-1, 17-19

Diagnosis: Trilete, mid-sized (40um), proximal face laevigate, distal cicatricosate with concentric ridges, intexine 1um thick, internally foveolate-micropitted, one grain found

Specimens: N 18, 4 x 86.7

Genus *Cicatricososporites* Pflug & Thomson in Thomson & Pflug 1953, emend. Potonie 1960

Cicatricososporites "decussatus"

Fig. A-1, 20-22

Diagnosis: Monolete, mid-sized (57um), cicatricosate, muri diagonal to laesura, 1um wide, 0.5um apart, one grain found

Specimens: PIN 55+30, 5.4 x 92.3

Discussion: *Cicatricososporites eocenicus* (Selling, 1944) Jansonius and Hills, 1987 has ridges parallel to laesura, *Cicatricososporites parallatus* (Mathur)Awad,1994 has striae almost parallel to striae mark (Awad, 1994).

Cicatricososporites eocenicus (Selling, 1944) Jansonius and Hills, 1987

Fig. A-2, 1-2

Diagnosis: Monolete, mid-sized (50-63um), cicatricosate, muri parallel to laesura, 1.5-2um wide, 0.5-1um apart.

Specimens: PIN 52+100, 6 x 102.6 PIN 28+0, 17.6 x 110

Genus *Clavatisporites* Kedves & Simoncsics 1964

Clavatisporites mutisi (Van der Hammen, 1954) Jaramillo *comb. nov.*

Fig. A-2, 3-4

Triletes mutisi Van der Hammen, 1954, p. 102, pl. 17.

Clavatriletes mutisi (Van der Hammen, 1954) Sarmiento, 1992, p. 63, pl. 1, figs. 1-2.

Diagnosis: Clavatrilete, mid-sized (31um), intexine 1.5um thick, clavae predominate but

also granules, baculae, and spines all in same grain, 0.5-1.5um high, 0.5-1.5u wide, 0.5-1.0.um apart, irregular, densely distributed, one grain found

Specimens: N 87, 14.1 x 85.5

Discussion: *Clavatriletes* Regali *et al.*, 1974 is a junior homonym and possible latter synonym of *Clavatriletes* Herbst, 1965, *Clavatriletes* Herbst, 1965 probably is a junior synonym of *Clavatisporites* Kedves & Simoncsics, 1964 (Jansonius and Hills, 1976, card 521).

Genus *Echinatisporis* Krutzsch 1959

Echinatisporis "brevispinosus"

Fig. A-2, 5-6

Diagnosis: Echitriletes, mid-sized (24-36um), intexine 1um thick, spines 3-5um high, 1.5-2um wide, ends pointed, uniformly shaped, densely distributed over entire grain, density and height of spines is variable.

Specimens: PIN 12, 6.3 x 98.5; RE 132, 21.2 x 90;PIN 81+0, 9.4 x 84.5

Discussion: *Echitriletes muelleri* Regali *et al.*, 1974 has larger spines (> 6um), wider spaced (6um), and spine tips are highly variable in same grain, *Echinatisporis minutus* Van der Kaars, 1983 has a trilete mark not always distinct, spines are shorter (<2.5um) and grain is smaller (16-26um) (Van der Kaars, 1983), *Echinatisporis* "obscurus" has two size-classes of spines, expanded at the base, and margo is indistinct.

Echinatisporis? "cingulatus"

Fig. A-2, 7-9

Diagnosis: Echitrilete, mid-sized (24-35um), cingulate, cingulum 1.5um thick, contact surface scabrate, remainder of grain echinate, 1-3um high, 1-2um wide.

Specimens: PIN 52+110, 7.4 x 81.5

Discussion: Unique combination cingulate-echinate. However, *Echinatisporites* Krutzsch 1959 is designated for azonotriletes microspores (Jansonius and Hills, 1976).

Echinatisporis "microechinatus"

Fig. A 2, 10-12

Diagnosis: Trilete, microechinate, mid-sized (27um), intexine thin, 0.5um thick, microspines <0.4u high, 0.7um wide, uniformly and densely distributed. One grain found

Specimens: PIN 19+60, 19.1 x 88.2

Discussion: *Echinatisporis minutus* Van der Kaars, 1983 has larger spines 1.5-2.5um high (Van der Kaars, 1983).

Echinatisporis "obscurus"

Fig. A-2, 13-15

Diagnosis: Echitrilete, mid-sized (23-34um), intexine 0.5-1um thick, trilete mark faint to indistinct, contact area laevigate to scabrate, two size classes: larger spines 1-2.5um high, 1.5-4um wide, greatly expanded at the base, smaller spines 0.5um wide/high scattered among the larger spines, density and height of spines are variable.

Specimens: N 110, 21.2 x 92.1; N 110, 3.6 x 91.9

Discussion: *Echinatisporis muelleri* (Regali *et al.* 1974) *n. comb.* has larger spines (> 6um), wider spaced (6um), and spine tips are highly variable in same grain (Regali *et al.* 1974), *Echinatisporis minutus* Van der Kaars, 1983 is smaller (16-26um), and spines are thinner (1um) (Van der Kaars, 1983), *Echinatisporis* "brevispinosus" has one size-class of spines, not expanded at the base, and margo is distinct, *Echinatisporis* "portae" has a raised laesura, and intexine is slightly scabrate.

Echinatisporis "portae"

Fig. A-2, 16-18

Diagnosis: Echitrilete, small-sized (24um), laesura raised and distinct, spines variable in shape and size in same grain, 0.5-2um high, 0.5um-2um wide, fairly distributes, intexine slightly scabrate, one grain found

Specimens: PIN 28+0, 5.2 x 87.1

Discussion: *Echinatisporis* "obscurus" has spines expanded at the base, and margo is indistinct.

Genus *Foveotriletes* Van der Hammen ex Potonie 1956

Foveotriletes "fossulatus"

Fig. A-2, 19-22

Diagnosis: Foveotriletes, mid-sized (30-35um), proximal face laevigate, distal face foveolate-fossulate, lumen 2-5um, 1-1.5um apart, radii long, margo absent to indistinct.

Specimens: PIN 81+0, 12.2 x 111.8; PIN 52+110, 5 x 82.3

Discussion: *Crassoretitriletes vanraadshooveni* Germeraad *et al.*, 1968 has a coarse reticula over entire grain (Germeraad *et al.*, 1968), *Foveotriletes margaritae* (Van der Hammen, 1954) Germeraad *et al.*, 1968 has sculpture over entire grain and it larger, 38-53um (Germeraad *et al.*, 1968).

Foveotriletes margaritae (Van der Hammen, 1954) Germeraad *et al.*, 1968

Fig. A-2, 23-24

Diagnosis: Foveotrilete, mid-sized (40-53um), intexine 1-2um thick, foveolae 0.5-2um wide, 1-2um part, radii short, laesura inconspicuous, sculpture width and coarseness is variable.

Specimens: PIN 63+20, 17.6 x 106

Genus *Ischyosporites* Balme 1957, emend. Fensome 1987

Ischyosporites "problematicus"

Fig. A-2, 25-28

Diagnosis: Trilete, mid-sized (30-40um), intexine 2um thick, fossulate, fossulae large, with undulating margins, bifurcating, and being connected with each other, 2um wide, 4-12um long, muri 3-4um wide, coarseness of fossulae is variable.

Specimens: N 110, 13.9 x 85.6; N 265, 12 x 114

Discussion: Other species of *Ischyosporites* Balme 57, emend. Fensome, 1987 has a shape of lumina is different being circular, polygonal or irregular in shape and generally isolated from each other (Jansonius and Hills, 1976), *Reticulatisporites* Ibrahim, 1933, emend. Neves, 1964 is cingulate and muri is thinner (Jansonius and Hills, 1976).

Genus *Kirchheimerisporites* Kedves 1995 ex Kedves, hoc loco

Kirchheimerisporites "tenuiradiatus"

Fig. A-2, 29-30

Diagnosis: Psilatriletes, mid-sized (24-29um), radially oriented internal thickenings, 1um wide, 2um long, 0.1-0.3um high. Size (24-29um)

Specimens: PIN 55+30, 5.1 x 99.5

Discussion: *Kirchheimerisporites khargaensis* Kedves, 1995 is larger (40-56um), and has other thickenings around the laesura (Kedves, 1995).

Genus *Laevigatosporites* Ibrahim 1933

Laevigatosporites "barcoi"

Fig. A-2, 31-33

Diagnosis: Monolete, mid-sized (33um), granular, granules <0.5um high/wide, irregularly distributed forming patches, intexine 0.4um, one grain found

Specimens: NA 46, 10 x 108.1

Discussion: *Laevigatosporites catanejensis* Muller *et al.* ,1987 has a thicker sporoderm (2.5um), and wider granules, about 1um wide (Muller *et al.*, 1987), *Laevigatosporites* "tenuiexinatus" has a thicker sporoderm (1um), and wider granules (0.5-0.8um).

Laevigatosporites "tenuiexinatus"

Fig. A-3, 1-3

Diagnosis: Monolete, mid-sized (50um), granular, granules <0.6um high, 0.5-0.8 wide, irregularly distributed forming patches, intexine 1um, one grain found

Specimens: PIN 28+0, 15.5 x 93

Discussion: *Laevigatosporites catanejensis* Muller *et al.* 1987 has a thicker sporoderm (2.5um), and wider granules, about 1um wide (Muller *et al.* 1987), *Laevigatosporites* "barcoi" has a thinner sporoderm (0.4um), and more narrow granules (<0.5um wide).

Laevigatosporites tibui (Van der Hammen 1956) Jaramillo *comb. nov.*

Fig. A-3, 4

Psilamonoletes tibui Van der Hammen, 1956, p. 108, pl. 2, fig. 6.

Diagnosis: Monolete, mid-sized (30-50um), elliptic, plane-convex to reniform, laevigate, sporoderm 0.5-1um thick, margo indistinct to slightly distinct.

Specimens: N 21+100, 6.6 x 91.1

Discussion: Srivastava (1971) considers *Psilamonoletes* Van der Hammen, 1956 a junior synonym of *Laevigatosporites* Ibrahim 1933, emend. Schopf, Wilson et Bentall 1944.

Genus *Microfoveolatosporis* Krutzsch 1959

Microfoveolatosporis skottsbergii (Selling, 1946) Srivastava, 1971

Fig. A-3, 5-6

Diagnosis: Foveomonolete, large-sized (60-89 um), foveolae 1.2-2 wide, 1um deep, 1-

1.5um apart, circular, uniform, densely distributed.

Specimens: PIN 81+0, 13.2 x 112; RE 67+120, 6.8 x 92.3

Genus *Osmundacidites* Couper 1953, emend. Norris 1986

Osmundacidites "dispergatus"

Fig. A-3, 7-9

Diagnosis: Monolete, mid-sized (30um), granular, granules 1-2um wide, <0.5um high, sparsely and unevenly distributed, one grain found

Specimens: N 18, 7.9 x 105

Discussion: *Osmundacidites wellmanii* Couper, 1953 is larger (40-63um wide), and exine thicker, 1.5um (Kedves, 1995), *Osmundacidites* "minor" is densely granular.

Osmundacidites "minor"

Fig. A-3, 10-12

Diagnosis: Trilete, mid-sized (25-30um), amb circular, intexine 1.0um, granular, granules densely distributed, radii long, laesura simple.

Specimens: PIN 63+20, 14.8 x 87.4

Discussion: *Osmundacidites wellmanii* Couper 1953 is larger (40-63um wide), and exine thicker, 1.5um (Kedves, 1995), *Hydrosporis farafraensis* Kedves 1995 is two layered (Kedves, 1995).

Genus *Polypodiaceoisporites* Potonie 1951 ex Potonie 1956

Polypodiaceoisporites? "fossulatus"

Fig. A-3, 13-16

Diagnosis: Trilete, mid-sized (33-46um), cingulate, laesura simple, proximal face verrucate or granular, distal face fossulate, sometimes kyrtomate, great variation in

coarseness and density of sculptural elements in proximal and distal faces, kyrtome sometimes developed.

Specimens: NA 46, 10.5 x 107.2; La Paz 886m, 20.7 x 88.5; UR 812, 5.3 x 97; PIN 75+160, 5.5 x 79.1; PIN 52+110, 6.7 x 112

Discussion: The genus *Polypodiaceoisporites* Potonie 1951 ex Potonie 1956 is very similar but has a reticulate distal face (Jansonius and Hills, 1976).

Genus *Polypodiisporites* Potonie 1931 ? in Potonie and Gelletich 1933 ex Potonie 1956, emend. Khan & Martin 1972

Polypodiisporites "brevis"

Fig. A-3, 17-18

Diagnosis: Monolete, ellipsoid, mid-sized (26-35um), verrucate, 2-2.5um wide, 1-2um high, rounded in plain view, flat, rounded and/or even baculae-like in cross section, rather scattered and variable spaced.

Specimens: UR 531+120, 14.8 x 110.7; UR 761, 20 x87

Discussion: *Verrucatosporites usmensis* (Van der Hammen 1956) Germeraad *et al.* 1968 is larger (39-61um), and has gemmae that are more widely and variable spaced (Germeraad *et al.*, 1968), *Polypodiisporites speciosus* Sah 1967 is larger (36-60um), and proximal face is laevigate (Sah, 1967), *Verrucatosporites* "protousmensis" .is larger (30-50um), and verrucae polygonal with sharp vertices.

Polypodiisporites "breviverrucatus"

Fig. A-3, 19-21

Diagnosis: Monolete, reniform, mid-sized (48-60um), proximal face scabrate, distal verrucate, verrucae flat,<0.3um high, forming a negative reticula.

Specimens: La Paz 712m, 17.6 x 106.5

Discussion: *Polypodiisporites specious* Sah 1967 has higher verrucae (0.5-2um high) (Sah, 1967) *Verrucatosporites usmensis* (Van der Hammen 1956) Germeraad *et al.*, 1968 is gemmate (Germeraad *et al.*, 1968).

Polypodiisporites "densus"

Fig. A-3, 22-24

Diagnosis: Monolete, ellipsoid, mid-sized (42-43um), gemmate, gemmae 2-5um wide, 2-4um high, globular to mushroom-like, densely distributed, diminishing around laesura height of sculpture is variable.

Specimens: PIN 81+0, 16.6 x 90

Discussion: *Verrucatosporites usmensis* (Van der Hammen, 1956) Germeraad *et al.*, 1968 has gemmae shorter (1.5-2.5um high), more widely and variable spaced (Germeraad *et al.*, 1968).

Polypodiisporites "echinatus"

Fig. A-4, 1-3

Diagnosis: Monolete, plane-convex, mid-sized (30-43um), echinate, spines 4-8um wide, 2-5um high, 2-5um apart, irregularly shaped, size and density of sculpture are variable.

Specimens: N 74, 15.5 x 108.5

Discussion: spiny sculpture has not been reported in other species of *Polypodiisporites*.

Polypodiisporites "pachyexinatus"

Fig. A-4, 4-6

Diagnosis: Monolete, mid-sized (39-48um), thick intexine 3um thick, proximal face laevigate, distal verrucate, verrucae flat,<0.5um high, verrucae 2-5um wide, fairly and irregularly distributed, interverrucae wall scabrate.

Specimens: N 174, 8.2 x 92

Discussion: *Polypodiisporites specious* Sah, 1967 has higher verrucae (0.5-2um high), densely distributed (Sah, 1967), *Verrucatosporites usmensis* (Van der Hammen, 1956) Germeraad *et al.*, 1968 is gemmate (Germeraad *et al.*, 1968).

Polypodiisporites "protousmensis"

Fig. A-4, 7-8

Diagnosis: Monolete, plane-convex, mid-sized (30-50um), verrucate, 2-5um wide, 0.5-1.2 apart, polygonal with sharp vertices, irregularly shaped and distributed, also with scattered baculae and gemmae, sculpturing has a very distinct dark color that contrast with light color of intexine, size and coarseness of sculpture are variable.

Specimens: N 21+100, 11.6 x 98.8

Discussion: *Polypodiisporites specious* Sah 1967 has a proximal face laevigate, verrucae has rounded vertices, and lack gemmae or baculae (Sah, 1967), *Verrucatosporites usmensis* (Van der Hammen, 1956) Germeraad *et al.* ,1968 is gemmate (Germeraad *et al.*, 1968)

Polypodiisporites specious Sah, 1967

Fig. A-4, 9-10

Diagnosis: Monolete, reniform, mid-sized (36-60um), proximal face laevigate, distal verrucate, verrucae irregular in shape and size, 1-4um wide, 0.5-2um high, 0.5-1.5 apart, size and coarseness of sculpture is variable.

Specimens: PIN 75+160, 10.2 x 78.8

Genus *Pteridacidites* Sah 1967

Pteridacidites "cucutensis"

Fig. A-4, 11-13

Diagnosis: Trilete, mid-sized (40um), cingulate, laesura simple, proximal face laevigate, distal face verrucate, few verrucae very large, isolated or fussed at the base.

Specimens: La Paz 712m, 15 x 88.4; La Paz 886m, 8.2 x 78.3

Discussion: *Pteridacidites africanus* Sah 1967 is larger (60-80um), and verrucae occur in proximal face (Sah, 1967).

Genus *Retitriletes* Pierce 1961

Retitriletes "enigmaticus"

Fig. A-4, 14-16

Diagnosis: Trilete, circular, mid-sized (40-60um), entire body reticulate, lumina 5-7um wide, hexagonal, muri thin, 2um high produced by a rise of exoexine.

Specimens: PIN 66+80, 5.5 x 84.2

Discussion: *Zlivisporis blanensis* Pacltova 1961 has proximal face laevigate (Pacltová, 1961). Here, I follow the opinion of Krutzsch 1963 that consider *Lycopodiumsporites* a nomen dubium, and suggest that all reticulate lycopodiaceoid tertiary forms should be assigned to *Retititriletes* Pierce 1961 (In Jansonius and Hills, 1976).

Genus *Tuberositriletes* Doring 1964

Tuberositriletes? "inciertus"

Fig. A-4, 17-19

Diagnosis: Trilete, mid-sized (26um), intexine 1um, verrucate, verrucae 0.5um high, circular, rounded or flat tip, widely and irregularly spaced, one grain found

Specimens: N 354+120, 15 x 107.7

Discussion: Tentatively is placed in *Tuberositriletes* Doring, 1964 although the amb is circular rather than triangular, and verrucae density is lower than type species, and verrucae density is lower than type species.

Tuberositriletes "verrucatus"

Fig. A-4, 20-22

Diagnosis: Trilete, mid-sized (27-32um), intexine 1um, verrucate, verrucae large, 2um high, well rounded in cross section, relatively even in shape and size, densely distributed over entire body.

Specimens: PIN 12, 10 x 94.9

Discussion: *Tuberositriletes*? "inciertus" has smaller verrucae (0.5um high), more widely distributed, *Distaverrusporites* Muller, 1968 has proximal face laevigate (Muller, 1968).

Genus *Zlivisporis* Pacltova 1964

Zlivisporis blanensis Pacltova, 1961

Fig. A-4, 23-24

Diagnosis: Trilete, circular, mid-sized (45-60um), proximal face laevigate, distal reticulate, lumina wide, hexagonal, muri thin, produced by a rise of exoexine.

Specimens: N 120, 18.3 x 95.4

GYMNOSPERM POLLEN

Genus *Araucariacites* Cookson and Couper 1953

Araucariacites "rugulatus"

Fig. A 5, 1-3

Diagnosis: Inaperturate, large-sized (66um), ellipsoidal, intectate 1.2um thick, rugulate, rugulae 1um wide, 3-5um long, 0.2um high, one grain found.

Specimens: N 149, 11.3 x 92.5

Discussion: *Araucariacites australis* Cookson, 1947 is thinner in poles and has a microrugulate to granular sculpture.

Araucariacites "scabratus"

Fig. A 5, 4-5

Diagnosis: Inaperturate, mid to large-sized (40-70um), intectate very thin 0.5um thick, densely scabrate..

Specimens: N 74, 14.5 x 104.7

Discussion: *Inaperturopollenites cursis* Sarmiento, 1992 is smaller and reticulate Sarmiento, 1992), *Araucariacites australis* Cookson, 1947 has a thicker exine (1-3um) and is commonly thinner in poles.

Genus *Ephedripites* Bolkhovitina 1953 ex Potonie 1958

Ephedripites vanegensis Van der Hammen and Garcia, 1966

Fig. A 5, 6

Diagnosis: Inaperturate, polyplicate, mid-sized (35-40um), atectate 0.8um thick, thicker at polar areas (1.2um), with a smooth zone at each pole of about 3-6um, 18-35 plicae.

Specimens: NA 59+90, 4.9 x 86.7; NA 46, 15.5 x 107

Genus *Laevigatasporites* Potonie and Gelletich 1933

Laevigatasporites "laevigatus"

Fig. A-5, 7-8

Diagnosis: Inaperturate, large-sized (85-120um), elliptic, psilate grain with atectate exine 1 to 1.9um thick.

Specimens: N 87, 8 x 81.5

Discussion: *Araucariacites australis* Cookson, 1947 is commonly thinner in poles and has a microrugulate to granular sculpture.

ANGIOSPERM POLLEN

Genus *Aglaoreidia* Erdtman 1960

Aglaoreidia? "foveolatus"

Fig. A-5, 9-11

Diagnosis: Monoporate, medium sized (42-43um), foveoreticulate, shape straight-convex, pore large, costate, exine 2um thick decreasing near poles, foveolate, foveolae 2um wide at equator gradually diminishing near poles.

Specimens: N 45, 14 x 111.2 N 45, 17.9 x 90.1

Discussion: *Aglaoreidia* Erdtman 1960 is the most similar genus although it is reticulate and lumina increase near pore except in the immediate vicinity of the pore (Jansonius and Hills, 1976).

Genus *Anacolosidites* Cookson and Pike, 1954, emend. Potonie 1960

Anacolosidites ariani (Sarmiento, 1992) Jaramillo *comb. nov.*

Fig. A-5, 12-13

Duplotriporites ariani Sarmiento, 1992, p. 88, pl. 12, figs. 1-2.

Diagnosis: Periporate, mid to large-sized (55-65um), six pores arranged in two triplets, symmetrically located in both sides of the equatorial plane, annulate, baculae fairly distributed, 2- 4um high, microbaculae 0.7-0.8um high, densely distributed.

Specimens: UR 531+120, 14.6x114.6; La Paz 712m, 16.9 x 103.8

Discussion: *Duplotriporites* Sarmiento 1992 is considered here a junior synonym of *Anacolosidites* Cookson & Pike 1954. There is not a unique characteristic separating *Duplotriporites* from *Anacolosidites*.

Genus *Baculamonocolpites* Sole de Porta, 1971

Baculamonocolpites "angustus"

Fig. A-5, 14-15

Diagnosis: Monosulcate, mid-sized (33um), marginate margo 3um wide, baculate, baculae 1.5 high, 1-2um wide, sparsely distributed over the surface, base slightly wider than tip. Tectum interbaculate is micropitted to scabrate", One grain found
Specimens: UR 761 7.4 X 97.9
Discussion: *Baculamonocolpites multispinosus* (Van der Hammen) Sole de Porta, 1971 is smaller (40-43 um), has thinner exine, and shorter baculae (Sole de Porta, 1971), Bacumorphomonocolpites *tausae* Sole de Porta, 1971 has larger and bifurcation baculae, *Racemonocolpites* Gonzalez 1967 has a higher baculae.

Baculamonocolpites "bimodalis"
Fig. A-5, 16-18
Diagnosis: Monosulcate, colpus indistinct, mid-sized (40um), two sculptural elements: baculae (2-4um high) and scabrae-microbaculae in the tectum interbaculae (<0.9um high), tectate, columellae indistinct, one grain found,
Specimens: PIN 32, 7 x 98
Discussion: *Echimorphomonocolpites* Gonzalez 1967 has a dominant echinate sculptural element, other *Baculamonocolpites* species do not have two types of sculptural elements (baculate and scabrate - microbaculate).

Baculamonocolpites "curubensis"
Fig. A-5, 19-22
Diagnosis: Baculamonosulcate, mid to large-sized (50-65um), intectate 2um thick, baculae 4-5um high, slightly wider at the tip, densely distributed, exine psilate in interbaculate areas, variable in density of baculae, from sparsely to densely distributed.
Specimens: PIN 52+110 6.6x97.1; PIN 32+0, 9.6 x 90.5
Discussion: *Racemonocolpites* Gonzalez 1967 have a predominant gemmate sculpture more densely distributed, *Baculamonocolpites multispinosus* (Van der Hammen) Sole de

Porta 1971 is smaller (40-43 um), nexine is thinner (1um), and baculae is sparsely distributed and not constrict (Sole de Porta, 1971).

Genus *Bacumorphomonocolpites* Sole de Porta, 1971

Bacumorphomonocolpites tausae Sole de Porta, 1971

Fig. A-5, 23-24

Diagnosis: Monosulcate, large-sized (90um), ellipsoidal, atectate (2um thick), baculate 2-20um long in same grain, longest baculae branches apically, one grain found.

Specimens: UR 502, 11.8 x 97.1

Genus *Bacutriporites* Jan du Chene, Onyike, and Sowunmi 1978

Bacutriporites "echinatus",

Fig. A-5, 25-26

Diagnosis: Bacutriporate, triangular-obtuse-convex, baculate to echinate, 4um high, 2um wide, tip always rounded. Tectum interbaculate is slightly scabrate, one grain found.

Specimens: PIN 42+100, 21.9x88.9

Discussion: Unique in combination of aperture and sculpture, *Echitriporites triangulifórmis* Van Hoeken Klinkenberg, 1964 is smaller and has shorter spines.

Genus *Bombacacidites* Couper 1960, emend. Krutzsch 1970

Bombacacidites annae (Van der Hammen, 1954) Germeraad *et al.*, 1968

Fig. A-6, 1-3

Diagnosis: *Bombacacidites*-type, mid-sized (25-50um), triangular-obtuse-convex, reticulate, muri pluricolumellate, lumina 1-3 wide in apocolpia and around colpi, diminishing toward mesocolpia, size and coarseness of reticulum is variable.

Specimens: N 21+100, 22.5x86.8; NA 59+90, 9.5 x 104.9; N 18, 5.5. x 83.4 N 110, 8 x 99.7

Bombacacidites brevis (Dueñas, 1980) Muller *et al.,* 1987

Fig. A-6, 4

Diagnosis: *Bombacacidites*-type, mid-sized (26-40um), triangular-obtuse-convex to circular, thin costae, reticulate, lumina constant over the entire grain, 0.8-0.9um, circular.

Specimens: PIN 28+0, 15.2 x 96.8; PIN 35+90, 5.9 x 80; PIN 63+20, 7.3 x 111; PIN 52+110, 16.6 x 112.1.

Bombacacidites "caldensis"

Fig. A-6, 5-7

Diagnosis: *Bombacacidites*-type, mid-sized (45um), elliptic, costae thin 1.2um wide, pores distinct, reticulate, lumina constant over the entire grain, 0.8-1um wide, one grain found.

Specimens: NA46, 7.9 x 84.5

Discussion: *Bombacacidites brevis* (Dueñas, 1980) Muller *et al.* 1987 is smaller (<40um), pores are indistinct, and margo is thinner (<1um wide) (Muller *et al.*, 1987), *Bombacacidites* "nissoides" is triangular-obtuse-convex, costae wider (3um wide), and pores indistinct.

Bombacacidites "dilcheroi"

Fig. A-6, 8-10

Diagnosis: *Bombacacidites*-type, mid-sized (36um), triangular-obtuse-straight, nexine thickening in mesocolpia, fossulate in apocolpia, foveolate in the mid-latitudes, and psilate in the mesocolpia, one grain found.

Specimens: RE 67+120, 21 x 99.3

Discussion: Differ from other *Bombacacidites* in its fossulate-psilate sculpture and the mesocolpia nexine thickenings.

Bombacacidites "etayoi"

Fig. A-6, 11-12

Diagnosis: *Bombacacidites*-type, mid-sized (33-40um), triangular-obtuse-straight, exine thin (0.7-1um), costae 1-2um wide, reticulate, lumina 0.5-0.8um at apocolpia to 0.5um at mesocolpia, transition is extremely gradual, lumina diameter at the apocolpium is variable.

Specimens: N110, 7.3 x 109.1 N149, 4.5 x 89.5

Discussion: *Bombacacidites nacimientoensis* (Anderson 1960) Elsik 1968 has a larger lumina, 2-4um wide (Elsik, 1968b), *Bombacacidites brevis* (Dueñas, 1980) Muller *et al.,* 1987 has uniform lumina, narrower margo (0.8-1um), and triangular-obtuse-convex to circular shape (Muller *et al.*, 1968).

Bombacacidites "fossureticulatus"

Fig. A-6, 13-14

Diagnosis: *Bombacacidites*-type, small to mid-sized (21-30um), triangular-obtuse-straight, fossulate at apocolpia and colpi margins to reticulate in mesocolpia.

Specimens: PIN 28+0, 13 x 98.5; PIN 28+0, 14 x 112

Discussion: *Bombacacidites foveoreticulatus* Muller *et al.*,1987 has a shorter colpi, thicker exine, larger lumina, and is foveoreticulate, *Bombacacidites* "protofoveoreticulatus" has a fossulate-foveolate lumina that is constant over entire grain.

Bombacacidites foveoreticulatus Muller *et al.*, 1987

Fig. A-6, 15-16

Diagnosis: *Bombacacidites*-type, mid-sized (35um), triangular-obtuse-straight, costae 3um wide, fossulate at apocolpia and colpi margins to reticulate at mesocolpia, one grain found

Specimens: PIN 81+0, 11.8 x 98.1

Bombacacidites "gentryi"

Fig. A-6, 17-19

Diagnosis: *Bombacacidites*-type, mid-sized (40um), circular, costae very thin, reticulate-foveolate at the apocolpia, 0.7um wide, grading to a more wider lumina at mesocolpia, 2-2.5um wide, one grain found.

Specimens: PIN 81, 4.6 x 87

Discussion: Unique *Bombacacidites* in having lumina of reticulum grading from foveolate at apocolpia to reticulate at mesocolpia. *Intratriporopollenites* Pflug & Thomson in Thomson & Pflug 1953 is vestibulate (Jansonius and Hills, 1976).

Bombacacidites nacimientoensis (Anderson, 1960) Elsik, 1968

Fig. A-6, 20-21

Bombacacidites nacimientoensis Anderson, 1960, p. 23, pl. 18, fig. 13.

Bombacacidites nacimientoensis (Anderson, 1960) Elsik, 1968b, p. 620, pl. 22, figs. 1-2, 4.

Bombacacidites bellus Frederiksen 1980 Muller *et al.* ,1987, p. 45, pl. 4, fig. 5 (*nomen nudum*)

Diagnosis: *Bombacacidites*-type, mid-sized (31-50um), triangular-obtuse-straight, reticulate, muri pluricolumellate, lumina 2-4m wide in apocolpia and around colpi, diminishing toward mesocolpia, transition although gradual, occurs in a narrow zone surrounding each angle of the grain.

Specimens: PIN 28, 18.6 x 100.3; PIN 12, 10.4 x 103

Discussion: *Bombacacidites annae* (Van der Hammen 1954) Germeraad *et al.* 1968 has a triangular-obtuse-convex shape, a shorter colpi, and a wider costa (3um). *Bombacacidites* "simplireticulensis" has a simplicolumellate muri.

Bombacacidites "nissoides"

Fig. A-6, 24-26

Diagnosis: *Bombacacidites*-type, mid-sized (46um), triangular-obtuse-convex, costae 3um wide, reticulate, lumina 1um wide constant over the entire grain, one grain found.

Specimens: PIN 63+20, 21 x 109.9

Discussion: *Bombacacidites brevis* (Dueñas, 1980) Muller *et al.*1987 is smaller (<40um) and margo is thinner , <1um wide (Muller *et al.*, 1987), *Bombacacidites* "caldensis" is elliptic, costae thinner 1.2um wide, and pores are distinct.

Bombacacidites soleaformis Muller *et al.*, 1987

Fig. A 7, 15-16

Diagnosis: *Bombacacidites*-type, mid-sized (34-45um), triangular-obtuse-concave, costae horseshoe-shaped, micropitted, lumina constant over entire body, variability mainly in coarseness of micropitting.

Specimens: RE 132m, 15.5 x 93; PIN 81+0, 8.1 x 93.1

Bombacacidites "protociriloensis"

Fig. A-6, 22-23

Diagnosis: *Bombacacidites*-type, mid-sized (30-44um), triangular-obtuse-concave, colpi long (CIp:0.5) reticulate, lumina 1.3-2um wide, constant over the entire surface of the grain, simplicolumellate, costae width and coarseness of reticula are variable.

Specimens: PIN 81+0, 8.2 x 115.2; PIN 42+100,18.7x 109.5

Discussion: *Bombacacidites ciriloensis* Muller *et al.* 1987 has a muri pluricolumellate and a shorter colpi (CIp:0.3), *Bombacacidites brevis* (Dueñas, 1980) Muller *et al.* 1987 has a narrower lumina (0.8-0.9um), *Bombacacidites* "nissoides" has a narrower lumina (1um).

Bombacacidites "protofoveoreticulatus"

Fig. A-7, 1-6

Diagnosis: *Bombacacidites*-type, mid-sized (30-40um), triangular-obtuse-convex, costae 3um wide, fossulate-foveolate over the entire grain.

Specimens: NA 46, 10.8 x 108.4; N 27, 8 x 98.9; N 27, 20 x 89.3; N 110, 18.3 x 95

Discussion: *Bombacacidites foveoreticulatus* Muller *et al.* ,1987 is foveolate-reticulate, and has a thicker exine (3um), *Bombacacidites* "fossureticulatus" is fossulate at apocolpia and colpi margins to reticulate at mesocolpia.

Bombacacidites "psilatus"

Fig. A-7, 7-9

Diagnosis: *Bombacacidites*-type, mid-sized (26-32um), triangular-obtuse-convex to straight, costae 1.5um wide, finely reticulate at apocolpium, lumina 0.8um wide decreasing gradually toward mesocolpia where is micropitted-psilate, coarseness of sculpture is variable.

Specimens: RE 67+120, 18.5 x 110; UR 781+20, 16.7 x 90.8; UR 761, 11.4 x 97.4

Discussion: *Bombacacidites brevis* (Dueñas, 1980) Muller *et al.* 1987 is more circular and has a larger lumina (0.8-0.9) constant over entire grain (Muller *et al.*, 1987), *Bombacacidites* "sabanensis" has a slightly protruding costae, lumina decrease abruptly, and it is larger (30-50um).

Bombacacidites "sabanensis"

Fig. A-7, 10-12

Diagnosis: *Bombacacidites*-type, mid-sized (30-50um), triangular-obtuse-straight, slightly protruding costae, reticulate at apocolpia and surrounding the colpi, lumina 0.8 wide, changing rather abruptly to psilate forming a triangle which vertices are 60 degrees offset.

Specimens: PIN 81+0, 14 x 91.4; PIN 52+110, 3.3. x 113

Discussion: *Bombacacidites* "psilatus" has a non-protruding costae, lumina decrease gradually, and it is smaller (26-32um).

Bombacacidites "simplireticulensis",

Fig. A-7, 13-14

Diagnosis: *Bombacacidites*-type, mid-sized (37-52um), triangular-obtuse-straight, colpi very short (Clp:0.1), costae 2-4um wide, reticulate, lumina 2-4 um wide, at vertices of grain sculpture abruptly changes to foveolate (lumina 0.5 wide) or psilate, simplicolumellate.

Specimens: PIN 28+0, 12 x 95; La Paz 886m, 10.7 x 103.5

Discussion: *Bombacacidites nacimientoensis* (Anderson 1960) Elsik 1968 has a longer colpi (Clp:0.45), narrower costae (2um), and a pluricolumellate muri (Elsik, 1968b), *Bombacacidites* "protonacimientoensis" has a narrower lumina (2um wide) that gradually diminishes to 1.1um toward mesocolpia, pluricolumellate.

Genus *Brevitricolpites* Gonzalez 1967

Brevitricolpites "macroexinatus"

Fig. A-7, 17-19

Diagnosis: Brevitricolporate, mid-sized (36um), echinate, spines long (3um), micropitted, exine tectate thickening around pores and underneath spines, one grain found

Specimens: PIN 81+0, 19.2 x 83.5

Discussion: *Brevitricolpites* "microechinatus" is intectate, *Brevitricolpites* "scabratus" has spines smaller (<1um), and exine does not thickens below spines, *Brevitricolpites variabilis* Gonzalez, 1967 is clavate to gemmate.

Brevitricolpites "microechinatus"

Fig. A-7, 20-23

Diagnosis: Brevitricolporate, mid-sized (28-42um), intectate, echinate, spines short (<1.1um), poricostate, variable in size and density of spines but never exceeding 1.1um high, a few grains 4-colporate

Specimens: N 110, 14.1 X 87.5; N 110, 6.5 x 86.7; N 119, 4.1 x 87

Discussion: *Brevitricolpites* "macroechinatus" is tectate and has spines higher (3um), *Brevitricolpites* "scabratus" is tectate (1um thick), *Brevitricolpites variabilis* Gonzalez, 1967 is clavate to gemmate.

Brevitricolpites "scabratus"

Fig. A-8, 1-3

Diagnosis: Brevitricolporate, inter-triangular, mid-sized (35um), poricostate, costae protruding, microechinate, spines conical, blunted, <0.8 high, fairly distributed, tectate, one grain found

Specimens: N 148, 20.4 x 102.8

Discussion: *Brevitricolpites* "microechinatus" is intectate, *Brevitricolpites* "macroexinatus" has spines higher (3um), and exine thickens below spines, *Brevitricolpites variabilis* Gonzalez 1967 is clavate to gemmate.

Genus *Clavamonocolpites* Gonzalez, 1967 emend. Muller *et al.*, 1987

Clavamonocolpites "macroclavatus"

Fig. A-8, 4-6

Diagnosis: Clavamonosulcate, mid-sized (42-45um), thick exine 2um, tectate, sulcus costate, clavae 2um high, scabrae interclavae.

Specimens: PIN 71+0, 7.5 x 83.8

Discussion: Differ from other *Clavamonocolpites* in the clavate-scabrate sculpture.

Genus *Clavatricolpites* Pierce, 1961

Clavatricolpites "densoclavatus"

Fig. A-8, 7-10

Diagnosis: Tricolpate, mid-sized (26-42um in polar view), short clavae, densely arranged in rows, or pseudocroton, or random pattern, intectate, nexine 0.8um, 3-5 colpate.

Specimens: PIN 28+0, 4.2 x 88.2; PIN 42+100, 19.6 x 107.5; PIN 81+0, 12.5 x 80; PIN 42+100, 10.6 x 91; RE 67+120, 13 x 104.5; PIN 52+100, 15 x 111.6

Discussion: *Clavatricolpites gracilis* Gonzalez, 1987 is marginate, *Crototricolpites* "protoannemariae" has a well defined croton pattern, *Crototricolpites americanus* Wijmstra, 1971 has a columellae digitate (Wijmstra, 1971).

Genus *Colombipollis* Sarmiento, 1992

Colombipollis tropicalis Sarmiento, 1992

Fig. A-8, 11

Specimens: N 74, 10.2 x 88.8

Genus *Cricotriporites* Leidelmeyer, 1966

Cricotriporites guianensis Leidelmeyer, 1966

Fig. A-8, 12-13

Cricotriporites operculatus Van Hoeken Klinkenberg, 1966, p. 39, pl. 1, fig. 16

Cricotriporites guianensis Leidelmeyer, 1966, p. 54, pl 4, fig. 4

Diagnosis: Psilatriporate, ellipsoid, small to mid-szed (24-32um), tectate (1um), pores costate, circular, occasionally operculate, operculum sometimes absent, psilate to finely scabrate.

Specimens: RE 67+120, 19 x 111.9

Discussion: No distinct morphological differences between *C. guianensis* and *C. operculatus* holotypes were found after examination of both holotypes at the Amsterdam collection.,

Cricotriporites "macropori"

Fig. A-8, 14-17

Diagnosis: Psilatriporate, ellipsoid, mid-sized (30-50um), intectate (0.5um), pores annulate (2um wide), circular (5-9um), micropitted, psilate or scabrate.

Specimens: PIN 12, 17 x 91; PIN 75+160, 14.6 x 96.9; RE 67+120, 18 x 101.1; PIN 55+30, 13 x 105.7

Discussion: Muller 1968 uses genus *Triorites* for psilate, atectate triporates accepting the Couper description for the genus while rejecting the emendation of Potonie, 1960a. However, he does not consider the genus *Cricotriporites* Leidelmeyer, 1966. Here I accept the Potonie emendation for *Triorites* (In Jansonius and Hills, 1976) consequently using *Cricotriporites* for circular, finely scabrate-psilate-micropitted triporate grains. *Triorites minutipori* Muller 1968 is smaller (<30um) and pore width is smaller (<2um), *T. festatus* Muller 1968 has a smaller pore (3um in diameter), *T. tenuiaxis* Muller 1968 has a 3-4um high collar. *Cricotriporites guianensis* Leidelmeyer, 1966 is smaller, and has a thicker exine (1-2um).

Cricotriporites minutipori (Muller, 1968) Jaramillo *comb. nov.*

Fig. A-8, 18

Triorites minutipori Muller, 1968, p. 14, pl. 3, fig. 9.

Diagnosis: Psilatriporate, small t0 mid-sized (<30um), atectate, exine very thin (<0.5um), pores costate, <2um in diameter, psilate to finely scabrate.

Specimens: PIN 42+100, 7.1 x 82.5

Discussion: *Triorites* Erdtman 1947 ex Cookson 1950 emend. Potonie 1960 has a 4-layered exine (Jansonius and Hills, 1976).

Cricotriporites "porielongatus"

Fig. A-8, 19-21

Diagnosis: Psilatriporate, ellipsoid, mid-sized (26-35um), atectate (1um), pores annulate, lalongate (6-8um).

Specimens: PIN 63+20, 10.9 x 110; PIN 55+30, 16.3 X 113

Discussion: *Cricotriporites* "macropori" is larger, has circular pores, a thinner exine, *Triorites minutipori* Muller, 1968 is smaller, *T. festatus* Muller 1968 has a smaller pore (3um in diameter), *T. tenuiaxis* Muller, 1968 has a 3-4um high collar, *Cricotriporites guianensis* Leidelmeye,r 1966 is smaller, and has a smaller pore (2.5 by 2um).

Genus *Crototricolpites* Leidelmeyer, 1966

Crototricolpites cf. *annemariae* Leidelmeyer, 1966

Fig. A-8, 22

Diagnosis: Tricolpate, mid-sized (48um), colpi simple, intectate 0.7um thick, clavate arranged in a croton pattern, clavae 1.5-2um high, one grain found.

Specimens: UR 531+120, 20.6 x 111

Discussion: The only difference with *Crototricolpites annemariae* Leidelmeyer, 1966 is that it has a slightly larger clavae (2-3um high).

Genus *Ctenolophonidites* Van Hoeken Klinkenberg,1966

Ctenolophonidites "cruciatus"

Fig. A-8, 25-26

Diagnosis: Ctenolophonidites, 4-colpate, mid-sized (50um), psilate, and with a cross-like ridge, one grain found

Specimens: PIN 28+0, 18.4 x 111.5

Discussion: *Ctenolophonidites costatus* (Van Hoeken-Klinkenberg, 1964) Van Hoeken-Klinkenberg, 1966 is 6-colpate and has a ring-like ridge (Van Hoken-Klinkenber, 1966), *Ctenolophonidites lisamae* (Van der Hammen and Garcia, 1966) Germeraad *et al,*. 1968 is smaller (17-31um) and scabrate (Germeraad *et al.*, 1968).

Genus *Curvimonocolpites* Leidelmeyer 1966

Curvimonocolpites inornatus Leidelmeyer, 1966

Fig. A-8, 27

Diagnosis: Monosulcate, mid-sized (29-35um) concave-convex shape in polar view, tectate, psilate.

Specimens: N 4, 13.3 x 101.

Genus *Cyclusphaera* Elsik, 1966

Cyclusphaera "scabratus

Fig. A-9, 1-2

Diagnosis: Its affinities are uncertain, elliptic grain, mid-sized (25-60um), two symmetric large openings lined by a thickening of the grain wall, scabrate-verrucate, tendency upsection in increasing the range of grain size toward larger sizes, also there is a trend in reducing size of sculpturing toward a fine scabrate, and reducing width of thickening lining aperture.

Specimens: N354+120, 5.9 x 89.2; PIN 81+0, 3.6 x 113

Discussion: *Cyclusphaera euribei* Elsik, 1966 does not exhibit a thickening of the wall surrounding the aperture, the wall is psilate, and openings are wider, *Cyclusphaera doubingeri* Salard-Cheboldaeff, 1978 is reticulate/perforate.

Genus *Echimonocolpites* Van der Hammen and Garcia, 1965

Echimonocolpites "tenuiechinatus"

Fig. A-9, 3-4

Diagnosis: Monosulcate, small to mid-sized (24-35um), sulcus long, exine reticulate, echinate, small elongate conical spines, spines size 2.5-3.5um high, 0.3-0.5 um wide.

Specimens: N 74, 11 x 103

Discussion: *Mauritiidites franciscoi* Van der Hammen and Garcia, 1966 has spines that are inserted in the tectum producing depressions in the exine, *Spinizonocolpites* Muller 1968, emend. Muller *et al.* 1987 has a zonocolpus (Muller *et al.*, 1987).

Genus *Echipericolpites* Van der Hammen and Garcia, 1965

Echipericolpites "brevicolpatus"

Fig. A-9, 5-7

Diagnosis: Pericolpate, mid-sized (27um), intectate, echinate, spines 1-1.5um high, surface interechinate micropitted, one grain found.

Specimens: N 120, 16.1 x 111.8

Discussion: Unique pollen grain in being echinate and pericolpate.

Genus *Echiperiporites* Van der Hammen and Wijmstra 1964, emend. Anzótegui 1996

Echiperiporites "scabratus"

Fig. A-9, 10-13

Diagnosis: Echiperiporate, large-sized (90um), pores annulate, large spines, 3-4um high, tectum scabrate, only one grain found.

Specimens: N 21+100, 12.1 x 110

Discussion: *Echiperiporites estelae* Germeraad *et al.* ,1968 has a micropitted tectum, and a smaller size (45-60um).

Echiperiporites estelae Germeraad *et al.*, 1968

Fig. A-9, 8-9

Diagnosis: Echiperiporate, mid-sizeD (45-60um), exine 1.6um thick, tectate, spines 4-7um tall, tectum interechinate micropitted, great variability in structure of exine (sometimes nexine is thicker), and spines dimensions and density, as well as pore density.

Specimens: PIN 28+0, 5.2 x 80.5 RE 251+30, 18.9 x 96.1

Genus *Echitetracolpites* Song, Qian and Zheng in Qian Zeshu, Zheng Yahui and Song Zhichen, 1993

Echitetracolpites "echinatus"

Fig. A-9, 14-15

Diagnosis: Stephanocolporate, mid-sized (30-40um), exine 1.5um, colpi very short, echinate, spines long, 2um high, tectum interechinate is micropitted.

Specimens: PIN 28+0, 18.9 x 105.5

Discussion: *Echitetracolpites* "tenuiexinatus" has a thinner exine (0.8um), two classes of spinae, and colpi less distinct, *Echitetracolpites jiangsuensis* Song *et al.* 1993 (in Qian Zeshu *et al.* 1993) is colpate (Jansonius and Hills, 1976).

Echitetracolpites "tenuiexinatus"

Fig. A-9, 16-18

Diagnosis: Stephanocolporate, mid-sized (35-50um), exine thin 0.5-0.8um, colpi very short, echinate, two groups of spinae, a large 1.3-2um high, and a small, 0.5-0.8um high, tectum interechinate is micropitted, variability in the length of the colpi, frequently being indistinct.

Specimens: PIN 52+100, 4.7 x 94.5; PIN 42+100, 15.7x104.5; PIN 42+100, 18.3 x 85

Discussion: *Echitetracolpites* "echinatus" has a thicker exine (1.5um), only one class of spinae, diameter of micropitting is larger, costae are better developed, and colpi are more distinctive, *Echitetracolpites jiangsuensis* Song *et al.*, 1993 (in Qian Zeshu *et al.*, 1993) is colpate (Jansonius and Hills, 1976).

Genus *Echitricolpites* Regali *et al.*, 1974

Echitricolpites "linearis"

Fig. A-9, 19-21

Diagnosis: Echitricolpate, mid-sized (50-60um), prolate, tectate, thin exine 0.7um thick, colpi costate, intruding, lined by a row of spines, spines arranged in longitudinal rows 5-6um apart, spines 0.8um high, tectum micropitted.

Specimens: N 110, 4.1 x 82.3 N 120, 15 x 109

Discussion: *Cristaecolpites echinatus* Schrank,1994 is smaller (33um), with two colpus-like furrows, and spines longer (15-2.5um high).

Genus *Echitriporites* Van der Hammen, 1956b ex Van Hoeken Klinkenberg, 1964

Echitriporites "annulatus"

Fig. A-9, 22-23

Diagnosis: Echitriporate, mid-sized (29um), pores costate, costae 2um wide, tectate, exine 1.1um, spines small, 0.8um high, fairly distributed over the entire grain, one grain found.

Specimens: PIN 55+30, 7 x 91.5

Discussion: *Echibrevitricolporites* "microechinatus" has an intectate exine and short colpi.

Echitriporites "retiechinatus"

Fig. A-9, 24

Diagnosis: Echitriporate, mid-sized (30-37um), annulate, annuli 2um wide, tectate, exine 1.5um thick, spines 2um high, fairly distributed over the entire grain, tectum interechinate is finely reticulate.

Specimens: RE 113, 7 x 88.6

Discussion: *Echitriporites nuriae* Dueñas, 1980 is larger (38-47um), with larger spines (up to 6um high), and thinner exine (1um thick), *Echitriporites* "variabilis" is triangular-acute-convex, has spines with rounded ends, and tectum is micropitted.

Echitriporites "spissuexinatus"

Fig. A-9, 25-26

Diagnosis: Echitriporate, mid-sized (50um), annulate, annuli 0.4um wide, intectate, exine 4um thick, spines 5um high, one grain found

Specimens: N18, 18.4 x 94.2

Discussion: Unique echinate triporate intectate with very thick nexine.

Echitriporites trianguliformis var. "orbicularis"

Fig. A-10, 1-2

Echitriporites trianguliformis forma A Muller *et al.*, 1987, p. 41, pl. 3, fig. 5.

Diagnosis: Echitriporate, small to mid-sized (22-32um), circular, pores costate, intectate 0.7um thick, spines 0.8-2.1um long, 0.5um at the base, 0.5um apart, large variation in grain size and spines length.

Specimens: PIN 12, 7.3 x 83.5; PIN 12, 8 x 86.5; PIN 35+90, 15 x 83.8

Discussion: This variety is more rounded and with spines more densely distributed than grains of *Echitriporites trianguliformis* Van Hoeken-Klinkenberg, 1964 from Late Cretaceous strata.

Echitriporites "variabilis"

Fig. A-10, 3-5

Diagnosis: Echitriporate, mid-sized (26-49um), triangular-acute-convex, pores costate, tectate 1.5um thick, larger grains with more and larger spines (3um high), shorter grains with less and shorter spines (1.5um high), tectum micropitted,

Specimens: PIN 47+100, 87.8 x 5.7; PIN 28+0, 14.1 x 105.1

Discussion: *Echitriporites nuriae* Dueñas 1980 has larger spines (up to 6um high), and thinner exine (1um thick), *Echitriporites* "retiechinatus" is elliptic, has spines with pointed ends, and tectum is finely reticulate.

Genus *Foveodiporites* Varma and Rawat, 1963

Foveodiporites guianensis Wijmstra, 1971

Fig. A-10, 6-7

Diagnosis: Diporate, rectangular, mid-sized (30-36um), foveolate, foveolae 0.5-0.8um wide, circular, 7-8um apart, increasing in density near pores.

Specimens: N4, 6.5 x 110.8

Genus *Foveotricolpites* Pierce, 1961

Foveotricolpites "costatus"

Fig. A-10, 8-10

Diagnosis: Tricolpate, mid-sized (33um), costae 4um wide, tectate 2.7um thick, foveolate, two class sizes distributed over entire grain, a large foveolae, 3um wide, and a smaller 1-2um wide, one grain found.

Specimens: PIN 12, 4 x 100.5

Discussion: *Foveotricolpites perforatus* Van der Hammen and Garcia, 1966 has foveolae 1-2um wide that increase in width toward poles.

Foveotricolpites perforatus Van der Hammen and Garcia, 1966

Fig. A-10, 11-12

Diagnosis: Tricolpate, prolate, mid-sized(30-50um), tectate 2-3um, foveolate, foveolae 1-2um wide, coarser on poles up to 5um, variability in thickness of exine layers.

Specimens: N149, 15.9 x 88.2; NA 59+90, 17.8 x 110.3

Foveotricolporites "brevicolpatus"

Fig. A-10, 13-15

Diagnosis: Tricolporate, mid-sized (36um), tectate 1um, short colpi, endopore costate and fastigiate, foveolate, lumina decrease from poles to equator, one grain found

Specimens: PIN 12, 10 x 87

Discussion: Unique combination of short colpi, fastigiate endopores and foveolae that diminish in width toward equator.

Genus *Foveotricolporites* Pierce, 1961

Foveotricolporites "fossulatus"

Fig. A-10, 16-17

Diagnosis: Tricolporate, mid to large-sized (40-61um), colpi marginate, pore costate, fossulate/foveolate diminishing toward colpi margines where is micropitted, thick nexine.

Specimens: PIN 52+110, 7.9 x 89.9

Discussion: *Retitricolporites quadrosi* Regali *et al.*, 1974 has a costate colpi and indistinct pores, *Foveotricolporites crassiexinatus* Van Hoeken Klinkenberg, 1966 is smaller (31um), and has an uniform foveolae.

Foveotricolporites "marginatus"

Fig. A-10, 18-19

Diagnosis: Tricolporate, mid-sized (30um), colpi marginate, pore simple, lalongate, fossulate, fossulae diminishing toward colpi margines and poles where is micropitted, nexine thick, one grain found.

Specimens: PIN 52+110, 17.9 x 82.5

Discussion: *Retitricolporites quadrosi* Regali *et al.*, 1974 has a costate colpi and indistinct pores, *Foveotricolporites crassiexinatus* Van Hoeken Klinkenberg, 1966 is smaller (31um), and has an uniform foveolae, *Foveotricolporites* "fossulatus" is larger (40-61um) and poricostate, *Foveotricolporites voluminosus* Gonzalez, 1967 has a thinner exine (1.8um), poricostate, and foveolate is uniform.

Foveotricolporites "microreticulatus"

Fig. A-10, 20-21

Diagnosis: Tricolporate, mid-sized (30um), prolate, colpi costate, tectate 1.2um thick, fossulate, fossulae 1-2um long, 0.4um wide, tectum interfossulate is micropitted, one grain found.

Specimens: N 354+120, 14.9 x 96.5

Discussion: *Foveotricolporites* "poricostatus" is poricostate, *Foveotricolporites* "rugulatus" has a thicker tectum (1um), longer fossulae (2-5um long), and tectum interfossulate is psilate.

Foveotricolporites "poricostatus

Fig. A-10, 22-23

Diagnosis: Tricolporate, mid-sized (36-40um), circular, tectate 2um thick decreasing toward colpi, endopores costate, fossulate, fossulae 2-4um long, evenly distributed over entire grain

Specimens: N 174, 5.7 x 99

Discussion: *Foveotricolporites* "microreticulatus" is colpicostate, *Foveotricolporites* "rugulatus" has a thicker tectum (1um), and colpi costate.

Foveotricolporites "rugulatus"

Fig. A-10, 24-25

Diagnosis: Tricolporate, mid-sized (28-45um), prolate, fossulate, tectate 1.5-1.8 thick, tectum very thick, ectocolpi costate, fossulae 2-5um long, branching, occasionally fossulae profusely fuses forming a rugulate-like pattern, coarseness of sculpturing and branching pattern of fossulae are variable

Specimens: RE 251+30, 18.1 x 88.7; PIN 12, 19.2 x 101

Discussion: *Foveotricolporites* "poricostatus" is poricostate, *Foveotricolporites* "microreticulatus" has a thinner tectum, shorter fossulae (1-2um long), and tectum interfossulate is micropitted

Genus *Foveotriporites* Gonzalez, 1967

Foveotriporites hammenii Gonzalez, 1967

Fig. A-10, 26

Diagnosis: Triporate, mid to large-sized (42-75um), pore costate, tectate 3um thick, foveolate, lumina 1.5-3.5um wide, foveolate to near reticulate sculpturing

Specimens: UR 812, 13 x 96.5 PIN 71+0, 13.2 x 108.5

Foveotriporites "poricostatus

Fig. A-11, 1-4

Diagnosis: Triporate, mid-sized (50um), costae thick, tectate 1u thick, foveolate, lumina 0.5um wide.

Specimens: PIN 81+0, 16.3 x 105.5; PIN 81+0, 19.1 X 89.7

Discussion: *Foveotriporites hammeni* Gonzalez 1967 has a thicker exine (3um) and larger foveolae (1.5-3.5 um).

Genus *Gemmamonocolpites* Van der Hammen and Garcia, 1965

Gemmamonocolpites "ambigemmatus"

Fig. A-11, 5-6

Diagnosis: Gemmamonosulcate, mid-sized (35-40um), intectate 0.5um thick, two types of sculpturing, a large gemmae sparsely distributed, mushroom-like, 2um high, and a small clavae, densely distributed, 1um high, density of large gemmae is variable.

Specimens: UR 812, 21 x 84.4

Discussion: *Gemmamonocolpites* "perfectus" is more densely gemmate and exine intergemmae is scabrate, *Gemmamonocolpites* "megagemmatus" has larger gemmae (4-5um high), *Racemonocolpites* Gonzalez 1967 has gemmae densely distributed.

Gemmamonocolpites gemmatus (Van der Hammen, 1954) Van der Hammen and Garcia, 1966

Fig. A-11, 7-8

Diagnosis: Gemmamonosulcate, samll to mid-sized (24-33um), intectate 0.5um thick, gemmae 0.3-1.5um high, fairly to moderately distributed, variable in density of larger gemmae, from sparsely to moderately distributed, but always shorter than 1.5 um

Specimens: N 4, 7.8 x 100.5 N 45, 20 x 87.1

Gemmamonocolpites "mammiformis"

Fig. A-11, 9-10

Diagnosis: Gemmamonosulcate, mid-sized (32um), intectate 0.8um thick, gemmae 2um high, sparsely distributed, exine at the base of the gemmae rises giving the appearance of a mammary gland, one grain found

Specimens: N 18, 11.5 x 94

Discussion: *Gemmamonocolpites* "perfectus" has spherical gemmae and exine thickness is constant, *Gemmamonocolpites* "megagemmatus" has larger gemmae (4-5um high). *Gemmamonocolpites macrogemmatus* Muller *et al.,* 1987 has large gemmae (up to 3um high), and exine thickness .

Gemmamonocolpites "megagemmatus"

Fig. A-11, 11-13

Diagnosis: Gemmamonosulcate, mid-sized (42um), intectate 0.5um thick increasing to 2um below gemmae, gemmae in two size-classes, a gemmae 4-5um high, and other group 1-1.5um high.

Specimens: PIN 52+110, 18.8 x 87.1; PIN 52+110, 5.2 x 111.4

Discussion: *Gemmamonocolpites* "mamiformis" has shorter gemmae (2um high), *Gemmamonocolpites* "ambigemmatus" has a shorter gemmae (2um high), and thickness of exine is constant, *Gemmamonocolpites macrogemmatus* Muller *et al.,* 1987 has shorter gemmae (up to 3um high).

Gemmamonocolpites "perfectus"

Fig. A-11, 14-15

Diagnosis: Gemmamonosulcate, mid-sized (40um), intectate 0.5um thick , gemmae 1-2um high, sparsely distributed up to 40 gemmae/grain, intergemmae exine scabrate, scabrae densely distributed, variable in size and density of gemmae.

Specimens: PIN 52+110, 11 x 86

Discussion: *Gemmamonocolpites* "ambigemmatus" is less densely gemmate and has small clavae densely distributed, *Gemmamonocolpites gemmatus* (Van de Hammen, 1954) Van der Hammen and Garcia, 1966 is smaller (24-28um), gemmae is smaller (0.3-1.5um), and lack a densely distributed scabrae, *Gemmamonocolpites* "mammiformis" has a mamiform-like gemmae and exine thickens below the sculpturing elements, Gemmamonocolpites *macrogemmatus* Muller *et al.,* 1987 has larger gemmae (up to 3um high), and exine is thicker (1um), *Racemonocolpites* Gonzalez 1967 has gemmae densely distributed.

Genus *Jandufouria* Germeraad *et al.*, 1968

Jandufouria "minor"

Fig. A-11, 16-18

Diagnosis: Stephanocolporate, mid-sized (26-36um) with a even and dense fine reticulum, circular lumina 0.5um wide, 4-6 colpores.

Specimens: PIN 63+20, 4.3 x 84

Discussion: Very similar to *Jandufouria seamrogiformis* Germeraad *et al.,* 1968 but *J. seamrogiformis* is consistently larger (range of 40-57um) and with a larger colpi, reaching half-way the poles, *Retistephanocolpites angeli* Leidelmeyer, 1966 is larger (35-50), colpate, with a thicker tectum (2.2um) and has a larger lumina that tends to be elongated and angular, *Retistephanocolpites tropicalis* Dueñas, 1980 is 4-colpate and colpi is not costate, *Retistephanocolporites quadriporus* Van der Hammen and Wymstra, 1964 has 4 pores and 4 colpi.

Genus *Jussitriporites* Gonzalez 1967

Jussitriporites "psilatus"

Fig. A-11, 19-21

Diagnosis: Triporate, mid-sized (28-40um), atectate 0.6um thick, psilate, costae well developed, protruding, costa width is variable (2-4um), sometimes in tetrads.

Specimens: N 4, 16.5 x 100 N 27, 13.3 x 91.6 N 110, 6.2 x 82.3

Discussion: *Jussitriporites undulatus* Gonzalez 1967 has a thicker tectate exine (3.2um), larger size (54-61um), and a psilate-verrucate sculpture.

Jussitriporites undulatus Gonzalez, 1967

Fig. A-11, 22

Diagnosis: Triporate, mid-sized (36-50um), exine 2-3.2um thick, costae very well developed and protruding, with an undulating rugulate sculpture, density of rugulae is variable from almost psilate to highly rugulate.

Specimens: PIN52+110, 3.8 x 101.8; PIN75+160, 17.3 x 87.9; RE 132, 20.5 x 113

Genus *Ladakhipollenites* Mathur and Jain, 1980

Ladakhipollenites "gemmatus"

Fig. A-11, 23-24

Diagnosis: Psilatricolpate, mid-sized (28um), colpi simple, colpi membrane ornamented with gemmae, one grain found.

Specimens: RE 67+120, 6.3 x 112.8

Ladakhipollenites rubini (Van der Hammen, 1954) *comb. nov*

Fig. A-11, 25-26

Tricolpites rubini Van der Hammen, 1954, p. 93, pl. 8.

Diagnosis: Psilatricolpate-colporate, small-sized (11-14um), colpi long, costae well defined, tectate, pores absent or present.

Specimens: PIN 42+100, 4.6 x 103.2

Discussion: *Tricolpites* Van der Hammen, 1954 is illegitimate and a junior synonym of Bartsia (Jansonius and Hills, 1976, card 2971).

Ladakhipollenites simplex (Gonzalez, 1967) Jaramillo *comb. nov.*

Fig. A-11, 29

Psilatricolpites simplex Gonzalez, 1967, p. 27, pl. 1, figs. 3-3a.

Diagnosis: Psilatricolpate, mid-sized (28-32um),prolate, colpi long, slightly marginate, nexine thick, and columellae indistinct.

Specimens: RE 190+10, 3.5 x 103.1

Discussion: *Psilatricolpites* (Van der Hammen 1954b) Pierce 1961 is an obligate junior synonym of *Tricolpites* Van der Hammen 1954, because they have same type species, as the latter is illegitimate and a junior synonym of *Bartsia*, so is *Psilatricolpites* (vide *Psilatricolpites* (Jansonius and Hills, 1976, card 2233).

Genus *Longapertites* Van Hoeken Klinkenberg, 1964

Longapertites microfoveolatus Adegoke and Jan du Chene, 1975

Fig. A-11, 27-28

Diagnosis: Longaperturate, mid-sized (42-53um), with micropitted sculpturing and a very thin tectate wall, 0.8um thick.

Specimens: N 87, 18 x 81

Longapertites "ornatus"

Fig. A-12, 1-3

Diagnosis: Longaperturate, mid-sized (40-45um), semitectate 1.7um thick, large reticulate, lumina (4-6um wide) decreasing near colpus, simplicolumellate, it could be a gradation to *L. proxapertitoides reticuloides*, however the lumina is much wider in *L.* "ornatus".

Specimens: PIN 52+110, 2.9 x 99.9

Discussion: *Longapertites proxapertitoides var. reticuloides* Van der Hammen and Garcia, 1966 has a narrower reticulate lumina (1-3um) and thicker muri (1-1.5um), *Longapertites marginatus* Van Hoeken Klinkenberg, 1964 has a coarser reticulate pattern on the proximal side.

Longapertites proxapertitoides var. proxapertitoides Van der Hammen and Garcia, 1966

Fig. A-12, 4

Diagnosis: Longaperturate, mid to large-sized (34-70um), tectate 1.5um thick, foveolate, lumina 0.5-2um, lumina diameter varies from 0.5um to 2um, seems to be a gradual transition to *L. proxapertitoides var. reticuloides*.

Specimens: N 265, 13.4 x 93.5; N 265, 5.5 x 110.2; RE67+120,10.4 x 104.7

Longapertites proxapertitoides var. reticuloides Van der Hammen and Garcia, 1966

Fig. A-12, 5

Diagnosis: Longaperturate, mid to large-sized (35-50um), tectate 1.5-3um thick, reticulate, lumina 1-3um, lumina diameter varies from 1um to 3um, seems to be a gradual transition to *L. proxapertitoides var. proxapertitoides*.

Specimens: N 265, 8 x 84.3 N 265, 5.6 x 108.2

Genus *Luminidites* Pocknall and Mildenhall, 1984

Luminidites "colombianensis"

Fig. A-12, 6-8

Diagnosis: Trichotomosulcate, large-sized (35-46um), exine semitectate, 1um thick, reticulate, lumina 1um at poles diminishing gradually toward radial equatorial areas.

Specimens: PIN 28+0, 11.9 x 106.8

Discussion: *Syndemicolpites* Van Hoeken-Klinkenberg, 1964 is diplotrichotomosulcate, *Luminidites reticulatus* (Couper) Pocknall and Mildenhall, 1984 has a thicker exine (1-2um), wider lumina (4.5-9um) that decrease toward distal pole, pluricolumellate (Jansonius and Hills, 1985).

Genus *Margocolporites* Ramanujam 1966 ex Srivastava 1969, emend. Pocknall and Mildenhall 1984

Margocolporites vanwijhei Germeraad *et al.*, 1968

Fig. A-12, 9

Diagnosis: Retitricolporate, mid-sized (40-42um), costate, with wide margines, coarseness of sculpture is variable.

Specimens: RE 67+120, 6.9 x 107

Genus *Mauritiidites* Van Hoeken-Klinkenberg, 1964

Mauritiidites franciscoi var. franciscoi (Van der Hammen, 1956) Van Hoeken Klinkenberg, 1964

Fig. A-12, 10-15

Diagnosis: Echinate monosulcate, mid-sized (30-56um), with rooted spines, intectate 0.8-1.7 um, shape and size of spines are variable. The greatest variability seems to be in the middle Eocene (PIN 12-PIN 50).

Specimens: N21+100, 12 x 107.5; PIN 12, 3.3 x 104; PIN 12, 6.8 x97.9; PIN 28+0, 11.1 x 89; PIN 39+166, 8 x 79; PIN39+166, 17,9 x 85.2

Mauritiidites franciscoi var. minutus Van der Hammen and Garcia, 1966

Fig. A-12, 16

Diagnosis: Echinate monosulcate, mid-sized (25-33um), with rooted spines, intectate <0.9 um, size of spines 0.5-1.8um.

Specimens: N 354+120, 7.6 x 80.5

Discussion: *Mauritiidites franciscoi var franciscoi* Van der Hammen and Garcia, 1966 has larger spines (1.5-5um), a thicker exine (>0.8um), and in general a larger size. The grain seems to grade into *M. franciscoi franciscoi* but its retained as a separated species because its size-range approaches a normal distribution.

Mauritiidites franciscoi var. pachyexinatus Van der Hammen and Garcia, 1966

Fig. A-12, 17

Diagnosis: Echinate monosulcate, mid to large-sized (40-60um), with rooted spines, intectate >2 um, wall thickness 2-3um, spines size (2.5-5um high), shape conical, to subconical

Specimens: PIN39+166, 20.4 x 19.4 PIN 19+60, 8.4 x 87.3

Genus *Momipites* Wodehouse, 1933, emend. Nichols, 1973

Momipites africanus Van Hoeken Klinkenberg, 1966

Fig. A-12, 18-19

Diagnosis: Psilatriporate, mid-sized (26-30um), atectate 1um thick, triangular-obtuse-convex, pores slightly protruding, and atria slightly developed.

Specimens: N 21+100, 7.1 x 87.1; N 18, 8.9 x 87.1

Momipites "pachyexinatus"

Fig. A-12, 20-21

Diagnosis: Psilatriporate, mid-sized (38-46um), triangular-obtuse-convex, pores simple, border irregular, exine tectate thick (1.5um), columellae indistinct, atrium slightly developed, pore borders are highly irregular.

Specimens: PIN 32+0, 16.1 x 97.6

Discussion: *Momipites africanus* Van Hoeken Klinkenberg, 1966 is smaller (<25um), polar shape is more triangular, and exine is atectate and thinner (<1.2um), *Cricotriporites* Leidelmeyer, 1966 has a circular or elliptic shape, and pores are annulate or costate

Genus *Monoporopollenites* Meyer, 1956

Monoporopollenites annulatus (Van der Hammen, 1954) Jaramillo *comb. nov.*

Fig. A-12, 22-23

Monoporopollenites annulatus Van der Hammen, 1954, p. 90, pl. 6

Diagnosis: Monoporate, mid-sized (25-40um), psilate, tectate thin (0.6um thick), and a costate pore slightly protruding, aperture (2-4um), costae width (2-3 um).

Specimens: PIN 35+90, 18.2 x 82.4 N 354+120, 10.5 X 83.7

Discussion: *Monoporites* is a nodem nudum (Jansonius and Hills, 1976, card 1705). *Monoporopollenites* Meyer, 1956 includes monoporate, psilate grains (Jansonius and Hills, 1976).

Genus *Nothofagidites* Potonie 1960

Nothofagidites "huertasi"

Fig. A-12, 24-25

Diagnosis: Scabrastephanoporate, mid-sized (26-45um), pore circular, annulate, tectate exine very thin (0.6um), scabrae <0.7um high, fairly distributed, in larger grains several elements of the sculpture seem spines however always shorter than 0.7um.

Specimens: PIN 66+80, 10 x 95 PIN 66+80, 18.7 x 96.2

Discussion: *Echistephanoporites alfonsi* Leidelmeyer, 1966 is smaller (18-19um), and has clearly defined spines 1um high, *Nothofagidites* "lolongatus" has a lolongate pore and a wider annuli (2um), *Nothofagidites flemingii* (Couper 1953) Potonie 1960 has more pores (7-9), exine is thicker (1um), and annuli is thicker (2-3um) (Jansonius and Hills, 1976); *Polyatriopollenites* Pflug 1953 is atriate (Jansonius and Hills, 1976).

Nothofagidites "lolongatus"

Fig. A-12, 26-27

Diagnosis: Scabrastephanoporate, mid-sized (24-38um), pore lolongate, annulate, tectate very thin (0.8um), scabrae <0.5um high, fairly distributed.

Specimens: RE 241+40, 18 x 92.7

Discussion: *Echistephanoporites alfonsi* Leidelmeyer, 1966 is smaller (18-19um), and has clearly defined spines 1um high, *Nothofagidites* "huertasi" has a circular pore and a more narrow annuli (1-1.5um), *Verrustephanoporites* "gemmatus" has a larger sculpture (>0.7um), *Polyatriopollenites* Pflug 1953 is atriate, *Nothofagidites flemingii* (Couper 1953) Potonie 1960 is larger (37-54um), has more pores (7-9), is convex between pores in polar view, and more spaced granules (2-3um apart).

Genus *Perfotricolpites* Gonzalez, 1967

Perfotricolpites digitatus Gonzalez, 1967

Fig. A-12, 28

Diagnosis: Tricolpate, mid-sized (38um), finely reticulate, with digitate columellae.

Specimens: PIN 42+100, 9.2 x 96.5

Genus *Periretisyncolpites* Keiser and Jan du Chene, 1979

Periretisyncolpites giganteus Keiser and Jan du Chene, 1979

Fig. A-13, 1

Diagnosis: Syncolpate, large-sized (110um), ectocolpi marginate, tectate 8um thick, reticulate, lumina of variable shapes and sizes, 4um long, muri 3-4um wide, one grain found

Specimens: La Paz 712m, 10 x 81.2

Periretisyncolpites "inciertus"

Fig. A-13, 2-5

Diagnosis: Periretisyncolpate, large-sized (110-120um), with a reticula formed by a large lumina surrounded by several smaller lumina, only two intercolpia found.

Specimens: N 18, 7 x 97.6

Discussion: *Periretisyncolpites giganteus* Keiser and Jan du Chene, 1979 has a more even lumina, a larger number of columellae, and a small overall size, *Periretisyncolpites magnosagenatus* (Van Hoeken Klinkenberg) Keiser and Jan du Chene, 1979 has an uniform lumina size (Keiser and Jan du Chêne, 1979).

Genus *Perisyncolporites* Germeraad *et al.*, 1968

Perisyncolporites pokornyi Germeraad *et al.*, 1968

Fig. A-13, 6

Diagnosis: Syncolporate psilate, mid-sized (23-25um), tectate 3um thick, with colpi arranged in a complex pattern and pores < colpi, number and arrangement of colpi and pores is variable, sometimes sexine is lost and grain appears periporate.

Specimens: RE 241+40, 6 x 94.5; PIN 52+110, 5.7 x 84.5

Genus *Propylipollis* Martin and Harris, 1975

Propylipollis "pseudocostatus"

Fig. A-13, 7-9

Diagnosis: Psilatriporate, triangular-acute-straight, mid-sized (27um), with evenly distributed, very fine reticulation and segmented costae, one grain found

Specimens: PIN 12, 12.6 x 113

Discussion: *Proteacidites dehaani* Germeraad *et al.*, 1968 has a larger reticulum, coarser in interporate fields, and a continuous costa, *Proteacidites miniporatus* Van Hoeken Klinkenberg 1966 is scabrate, *Propylipollis amolosexinus* (Dettmann and Playford,

1968) Dettmann and Jarzen, 1996 is larger (35-56um), and thinner exine (2-3um thick) (Dettmann and Jarzen, 1996).

Genus *Proxapertites* Van der Hammen 1956, emend. Singh, 1975

Proxapertites cursus Van Hoeken Klinkenberg, 1966

Fig. A-13, 10

Diagnosis: Proxaperturate, mid to large-sized, with coarse and even reticulation" "Size 29-60um, thickness of exine

Specimens: NA 59+90, 12.8 x 108.5

Proxapertites humbertoides (Van der Hammen, 1954) Sarmiento, 1992

Fig. A-13, 11-12

Diagnosis: Proxaperturate, large-sized (73-121um), foveolate, foveolae lumina 2-6um, shape and degree of fusion of columellae is variable, lumina varies from circular to elongated to stellate or in a zig-zag pattern.

Specimens: N 74, 14.7 x 90; N 354+120, 8.2 x 89; PIN 12, 6.2 x 100.2; UR 531+120, 21 x 81.5

Proxapertites magnus Muller *et al.*, 1987

Fig. A-13, 13-14

Diagnosis: Proxaperturate, large-sized (60-95um) with foveolate lumina <1.5um, shape and density of columellae is variable, lumina diameter 0.8-1.5um.

Specimens: N 87, 6.2 x 84.5; N 27, 20.2 x 98.1; RE 67+120, 23 x 100

Proxapertites operculatus (Van der Hammen, 1956) Germeraad *et al.*, 1968

Fig. A-13, 15

Diagnosis: Proxaperturate, mid-sized, with fine even reticulation.

Specimens: NA 59+90, 4.9 x 84.1

Discussion: *Proxapertites cursus* Van Hoeken Klinkenberg, 1966 has a wider and less even lumina, and exine is thicker.

Proxapertites psilatus Sarmiento, 1992

Fig. A-13, 16-17

Diagnosis: Proxaperturate, mid-sized (25-37um), with psilate, scabrate to micropitted sculpturing and a thin tectate exine, 0.8um-1.2um thick, sculpturing being scabrate to psilate to micropitted.

Specimens: N 354+120, 19.1 x 91.5; PIN 42+100, 5.5 x 100.5

Proxapertites verrucatus Sarmiento, 1992

Fig. A-13, 18-19

Diagnosis: Proxaperturate, mid-sized (27-35um), verrucate, density and high of verrucae is variable.

Specimens: UR531+120,14.8x102.9; UR 507, 10.5 x 97.1

Genus *Psilabrevitricolpites* Van Hoeken Klinkenberg, 1966

Psilabrevitricolpites "costatus"

Fig. A-13, 20-21

Diagnosis: Psilatricolpate, mid-sized (30um), colpi very short, costate, atectate 0.8um thick, psilate, one grain found.

Specimens: N18, 9.8 x 104

Discussion: *Lakiapollis* Venkatachala and Kar, 1969 is brevitricolporate (Jansonius and Hills, 1976).

Genus *Psilabrevitricolporites* Van der Kaars, 1983

Psilabrevitricolporites "costatus"

Fig. A-13, 22-23

Diagnosis: Psilatricolporate, mid-sized (40um), colpi very short, tectate, conspicuously poricostate, micropitted, one grain found.

Specimens: PIN 42+100,12.3x112.5

Discussion: *Psilabrevitricolporites* "operculatus" is smaller and operculate, *Lakiapollis* Venkatachala and Kar 1963 is psilate-scabrate (Jansonius and Hills, 1976).

Psilabrevitricolporites "operculatus"

Fig. A-13, 24-25

Diagnosis: Psilatricolporate, small-sized(19um), colpi very short, pore costate, psilate, one grain found.

Specimens: PIN 39+166, 16 x 100.5

Discussion: *Psilatricolporites operculatus* Van der Hammen and Wymstra, 1964 has a longer and marginate colpi, and operculum is wider (1.5 um).

Psilabrevitricolporites simpliformis Van der Kaars, 1983

Fig. A-14, 1-2

Diagnosis: Psilatricolporate, mid-sized (26-32um), triangular-acute-convex, colpi very short, pore costate, atectate 0.8um thick, psilate to finely scabrate, varies in the costae width, in the size of polar darkening, and sculpture type (psilate to finely scabrate).

Specimens: N 21+100, 12 x 107.1; N 21+100, 10 x 106.1; N 27, 12.5 x 100.5

Genus *Psilamonocolpites* Van der Hammen and Garcia, 1966

Psilamonocolpites grandis (Van der Hammen, 1954) Van der Hammen and Garcia, 1966

Fig. A-14, 3-4

Diagnosis: Psilamonosulcate, 30-60um long, atectate, exine 1um thick, sculpture psilate to micropitted

Specimens: N 4, 5.5 x 88.2

Discussion: Van der Hammen and Garcia, 1966 separates *P. grandis* from other three species of *Psilamonocolpites* on the basis of size. However, an overlap in sizes was found between *P. medius* and *P. grandis*. *P. grandis* is retained here because its distinctive thick exine (1um), thicker than *P. medius* (<0.5um).

Psilamonocolpites medius (Van der Hammen, 1954) Van der Hammen and Garcia, 1966

Fig. A-14, 5-6

Diagnosis: Psilamonosulcate, mid-sized (29-50um), atectate, exine <0.5 um thick, sculpture psilate to micropitted.

Specimens: N 74, 14 x 112.1

Discussion: Van der Hammen and Garcia, 1966 separates *P. medius* from other three species of *Psilamonocolpites* on the basis of size. Here it was found that there is an overlap in size between *P. medius* and *P. grandis*. However, *P. medius* is retained here because its distinctive thin exine (<0.5um).

Genus *Psilaperiporites* Puri 1963

Psilaperiporites "enigmaticus"

Fig. A-14, 7-8

Diagnosis: Psilaperiporate, small-sized (22um), circular, pores 9, 3 in equator, the other 6 opposite to each other half-way equator-pole, slightly annulate, atectate (1um), one grain found.

Specimens: NA -2, 16.8 x 91.5

Discussion: *Psilaperiporites* "pachyexinatus" has 12 pores, and it is tectate, *Anacolosidites luteoides* Cookson and Pike 1954 has six pores, it is tectate, and

subtriangular in polar view (Jansonius and Hills, 1985), *Cretacaeiporites mulleri* Herngreen, 1973 is tectate and has a scabrate pore membrane.

Psilaperiporites "pachyexinatus"

Fig. A-14, 9-10

Diagnosis: Periporate, small-sized (26um), psilate, pores 12, annulate, thick nexine and very thin sexine, one grain found.

Specimens: PIN 71, 15 x 107

Discussion: *Psilaperiporites* "pauciporatus" has 18-23 pores, and a micropitted sculpture.

Psilaperiporites "pauciporatus"

Fig. A-14, 12-13

Diagnosis: Periporate, small to mid-sized (20-32um), micropitted, pores 18-23, slightly annulate.

Specimens: PIN 12, 13.5 x 87.2

Discussion: *Psilaperiporites robustus* Regali *et al.*, 1974 has 60-64 pores, larger in diameter (4um), and a larger body size (45-48 um), *Scabraperiporites nativensis* Regali *et al.*, 1974 is scabrate.

Genus *Psilastephanocolpites* Leidelmeyer, 1966

Psilastephanocolpites "marginatus"

Fig. A-14, 14-16

Diagnosis: Psilastephanocolporate, mid-sized (53um), atectate 1um thick, and colpi marginate, one grain found

Specimens: PIN 81+0, 15 x 105

Discussion: *Psilastephanocolpites maia* Leidelmeyer, 1966 is tectate, has a thicker exine (1.8um), and is smaller (27um).

Psilastephanocolpites "punctum"

Fig. A-14, 17-18

Diagnosis: Stephanocolpate, densely micropitted, small-sized (26um), tectate 0.9um thick, and with very short costate colpi, one grain found

Specimens: PIN 42+100, 15.5 x 110

Discussion: *Psilastephanocolpites maia* Leidelmeyer, 1966 has a thicker exine (1.8um), and colpi is longer.

Genus *Psilastephanocolporites* Leidelmeyer 1966

Psilastephanocolporites "brevicolpatus"

Fig. A-14, 19-21

Diagnosis: Psilastephanocolporate, mid-sized (26-28um), tectate 0.7um thick, with very short 10-14 meridional ectocolpi, and a zonocolpus costate, columellae distinctiveness is variable.

Specimens: PIN 42+100, 6.9 x 109.5; PIN 52+110, 8 x 90.9

Discussion: *Psilastephanocolporites fissilis* Leidelmeyer, 1966 has meridional colpi almost reaching the polar areas, and a thicker exine (2 um), *Psilastephanocolpites globulus* Van der Kaars, 1983 has only 4 colpi, costa is thicker (2um), and exine is atectate, *Psilastephanocolporites globulus* Van Hoeken-Klinkenberg, 1966 does not have an equatorial colpus.

Psilastephanocolporites fissilis Leidelmeyer, 1966

Fig. A-14, 22-24

Diagnosis: Psilastephanocolporate, mid-sized (22-32um),, prolate, atectate 1.5-2.5um thick, with a meridional ectocolpi very long and a zonocolpus costate, costae thickness (0.5-2 um).

Specimens: PIN 28+0, 11.6 x 108.2; PIN 19+60, 9.4 x 98.5; PIN 52+110, 12.4 x 109.5

Discussion: *Psilastephanocolporites* "brevicolpatus" has a shorter meridional colpi, and a thinner exine (< 1 um).

Psilastephanocolporites "pachyexinatus

Fig. A-14, 25-28

Diagnosis: Psilastephanocolporate, large (45-53um), tectate (4-5um), nexine very thick, colpi large-sized, marginate by thinning of nexine, exine thickness (4-5um); 3-4-colporate.

Specimens: PIN 55+30, 13.5 x 85.1; PIN 28+0, 11.9 x 98; PIN 28+0, 8.1 X 97.6

Discussion: *Psilastephanocolporites* "psilatus" has a shorter colpi, and thinner exine (<2um).

Psilastephanocolporites "psilatus"

Fig. A-15, 1-2

Diagnosis: Psilastephanocolporate, large-sized (30-52um), tectate (1.5-2um), nexine very thick, colpi short to mid-sized, marginate by thinning of nexine, poricostate; 4-6-colporate, in few grains the colpi is larger, reaching half-way between the equator and the pole, costa thickness (0.5-2um)

Specimens: PIN 81 +0, 14 x 91.5; PIN 81+0, 17.8 x 110.8

Discussion: *Psilastephanocolporites* "pachyexinatus" has a larger colpi, and thicker exine (4-5um).

Genus *Psilastephanoporites* Regali, *et al.* ,1974 ex Hoorn, 1993

Psilastephanoporites "annulatus"

Fig. A-15, 3-4

Diagnosis: Psilastephanoporate, large-sized (42um), 4-porate, annulate, and atectate 1.2um thick., one grain found.

Specimens: UR 761, 16.2 x 86.9

Discussion: *Psilastephanoporites caribiensis* Dueñas, 1980 is smaller (26-31um), and tectate, *Psilastephanoporites stellatus* Regali *et al.* ,1974 has 6 pores in two groups of three, *Psilastephanoporites* "scabratus" has a thinner exine (0.5), annuli is more narrow (2um).

Psilastephanoporites "distinctus"

Fig. A-15, 5-6

Diagnosis: Psilastephanoporate, mid-sized (26-40um), rhombic, pores annulate, protruding and above equator.

Specimens: PIN 52+110, 11.2 x 85.6

Discussion: *Venezuelites globoannulatus* Muller *et al.*, 1987 has a thicker annulus (9um), and a thicker exine (2.5um).

Psilastephanoporites "scabratus"

Fig. A-15, 7-8

Diagnosis: Stephanoporate, mid-sized (31um), scabrate in poles, psilate in equator, 4-porate, pore intruding, annulate, atectate (0.5um), one grain found.

Specimens: N 149, 10.5 x 101.2

Discussion: *Psilastephanoporites caribiensis* Dueñas ,1980 is tectate, and exine is thicker (1.5um), *Psilastephanoporites stellatus* Regali *et al.,* 1974 has 6 pores in two

groups of three, *Psilastephanoporites* "annulatus" has a thicker exine (1.2), annuli is wider (5um),

Genus *Psilasyncolporites* Leidelmeyer ex Gonzalez, 1967

Psilasyncolporites "fastigiatus"

Fig. A-15, 9-10

Diagnosis: Psilasyncolporate, mid-sized (29um), colpi simple, pores costate, fastigiate, apocolpial field 10um wide, tectate 2um thick, columellae indistinct, sexine thick (1.2um), one grain found.

Specimens: RE 132, 19.5 x 111.1

Discussion: *Syncolporites poricostatus* Van Hoeken Klinkenberg, 1966 has a thinner exine (1.2um) and it is smaller (14.5 um).

Psilasyncolporites "psilatus"

Fig. A-15, 11-12

Diagnosis: Psilasyncolporate, small-sized (13um), colpi costate, poricostate, apocolpial field absent, tectate 1um thick, columellae distinct., one grain found.

Specimens: PIN 47+100, 12.8 x 89.5

Discussion: *Syncolporites* poricostatus Van Hoeken Klinkenberg, 1966 has a pore fastigiate, and a colpi simple, *Syncolporites incomptus* Van Hoeken Klinkenberg, 1964 is larger (20-23um), and apertures are simple, *Psilasyncolporites parcus* Gonzalez, 1967 has a thinner exine (<1um), and pores are simple.

Genus *Psilatricolporites* Van der Hammen 1956 ex Van der Hammen and Wijmstra, 1964

Psilatricolporites "crassicolumellatus"

Fig. A-15, 13-15

Diagnosis: Psilatricolporate, mid-sized (30um), with a thick exine (2um) and a distinct and long columellae, costae 1.2um thick foming a belt at the equator and decreasing gradually toward poles, one grain found

Specimens: PIN 52+110, 5.5 x 112

Discussion: *Psilatricolporites obscurus* Gonzalez, 1967 has a thicker exine (4.8um), and an equatorial colpus, *Psilatricolporites optimus* Gonzalez, 1967 has a perforate tectum and a costa is absent.

Psilatricolporites crassus Van der Hammen and Wymstra, 1964

Fig. A-15, 16

Diagnosis: Psilatricolporate, mid-sized-sized (33-55um),, colpi medium-sized, pore lalongate costate, tectum thick with columella clearly distinct, sculpturing and thickness of the wall extremely variable, a few grains are tricolpates.

Specimens: PIN 12, 12.3 x 84.5; PIN 12, 14.9 x 110

Psilatricolporites maculosus Regali *et al.*, 1974

Fig. A-15, 17-18

Diagnosis: Psilatricolporate, prolate, small to mid-sized (24-36um), colpi short to medium-sized, equatorial costa conspicuous, and pores lalongate.

Specimens: PIN 75+160, 20 x 87

Psilatricolporites operculatus Van der Hammen and Wymstra, 1964

Fig. A-15, 19

Diagnosis: Tricolporate, small-sized (18-21um), psilate-micropitted, operculate.

Specimens: PIN 39+166, 9.8 x 84.6

Psilatricolporites "orbicularis"

Fig. A-15, 20-22

Diagnosis: Psilatricolporate, mid-sized (25-33 um), tectate, colpi long, slightly marginate, pores circular, costate.

Specimens: RE 143+120, 20 x 93.7

Discussion: *Psilatricolporites* "poricostatus" is atectate, has a colpi shorter, and colpi is simple.

Psilatricolporites "poricostatus"

Fig. A-15, 23-24

Diagnosis: Psilatricolporate, triangular-obtuse-convex, small-sized (25um), colpi midsize, pores costate, atectate thin (0.5 um), one grain found

Specimens: PIN 42+100, 9.7 x 87.8

Discussion: *Psilatricolporites marginatus* Van der Kaars 1983 has a exine thicker, tectate, and a colpi costate, *Psilatricolporites* "orbicularis" is tectate, has a colpi longer, and colpi is slightly marginate.

Psilatricolporites "singularis"

Fig. A-15, 25-28

Diagnosis: Psilatricolporate, mid-sized (31 um), colpi marginate, pores with two rings, outer by thinning of nexine, inner by thickening of nexine, sexine absent near colpi, one grain found.

Specimens: PIN 42+100, 20.6 x 100.2

Discussion: Unusual double ring around pores has not been reported in any species.

Psilatricolporites "spongiosus"

Fig. A-15, 29-30

Diagnosis: Psilatricolporate, subprolate, mid-sized(30-41um), colpi long, equatorial costa very thick, and tectum spongy, continuous equatorial costa in not always well defined, sometimes the endexine thickening is only around pores without being interconnected with each other.

Specimens: N 149, 6.2 x 93

Discussion: *Psilatricolporites maculosus* Regali *et al.*, 1974 is very similar but exine is thinner (1.2um) and not spongy , colpi shorter (up to half-way pole-equator), and costa is thinner (1um), *Psilatricolporites transversalis* Dueñas, 1980 is smaller (20-22um), colpi is short and indistinct, and tectum is non spongy.

Psilatricolporites transversalis Dueñas, 1980

Fig. A-15, 31

Diagnosis: Psilatricolporate, subprolate, mid-sized (26-40um) with a highly protruding costa surrounding lalongate pores, very short indistinct colpi, and a equatorial band of endexine thickening, colpi length 0.5-8um, equatorial colpi sometimes absent to very tenuous.

Specimens: PIN 52+110, 9.7 x 110.4 N 131, 19.2 x 111.3

Discussion: *Psilatricolporites maculosus* Regali *et al.*, 1974 does not have a highly protruding costa, and colpi is distinct.

Psilatricolporites triangularis Van der Hammen and Wymstra, 1964

Fig. A-15, 32

Diagnosis: Psilatricolporate, small-sized (20-25um), triangular-obtuse-convex in polar view, and pores conspicuously costate.

Specimens: PIN 81+0, 10.9 X 87.6

Genus *Psilatriporites* (Van der Hammen, 1956) Mathur, 1966 ex Hoorn, 1993

Psilatriporites "tenuiexinatus"

Fig. A-15, 33-34

Diagnosis: Psilatriporate, triangular-acute-convex, mid-sized (30-31um), atectate, exine very thin (0.5um), annulate, annuli narrow and thin.

Specimens: UR 531+120, 12.3 x 106.2

Discussion: *Proteacidites dehaani* Germeraad *et al.*,1968 is reticulate, *Proteacidites miniporatus* Van Hoeken Klinkenberg, 1966 is scabrate and exine thicker, *Propylipollis* "pseudocostatus" is reticulate.

Genus *Racemonocolpites* Gonzalez, 1967

Racemonocolpites "costagemmatus"

Fig. A-16, 1-2

Diagnosis: Gemmamonosulcate, mid-sized (43-50um), sulcus costate, intectate 0.5um thick, gemmae 1-1.5um high, densely distributed over the entire grain.

Specimens: N 354+120, 9.9 x 93.5 PIN 71+0, 9.3 x 106

Discussion: *Racemonocolpites racematus* (Van der Hammen, 1954) Gonzalez, 1967 is shorter (36um), has larger gemmae (1.5-2um high), and a longer sulcus.

Racemonocolpites facilis Gonzalez, 1967

Fig. A-15, 35

Diagnosis: Gemmamonosulcate, mid-sized (35-50um), sulcus simple, intectate 0.5um thick, gemmae variable in shape and size within same grain, 3-4um high, densely distributed over the entire grain, slightly scabrate in intergemmate areas

specimens: UR 812, 13.9 x 104.4; La Paz 712m,13.5 x 83.5; PIN 66+80, 13.2 x 105.9

Racemonocolpites racematus (Van der Hammen, 1954) Gonzalez, 1967

Fig. A-16, 3-4

Diagnosis: Gemmamonosulcate, mid-sized (36-56um), colpi simple, intectate 0.5um thick, gemmae 1.5-2um high, densely distributed over entire grain.

Specimens: N 27, 8.2 x 85.7; RE 67+120, 16.2 x 99.4; UR 761, 14.7 x 111

Genus *Retibrevitricolpites* Van Hoeken Klinkenberg, 1966

Retibrevitricolpites "costatus"

Fig. A-16, 5-6

Diagnosis: Retibrevitricolpate, mid-sized (29-33 um), micropitted, lumina 0.5um wide, uniform, colpi costate.

Specimens: PIN 81+0, 17.9 x 80.8

Discussion: *Retibrevitricolporites* "speciosus" does not have an uniform lumina, *Retibrevitricolporites* "grandis" has a pore costate, and reticulate lumina wider (0.5-0.9), *Retibrevitricolpites* "santanderensis" has a thinner exine (1um), lumina is wider (0.7-0.9um) and costae is wider (3um).

Retibrevitricolpites retibolus Leidelmeyer,1966

Fig. A-15, 36-37

Retibrevitricolpites retibolus Leidelmeyer, 1966, p. 53, pl. 2, fig. 4.

Retibrevitricolpites increatus Gonzalez, 1967, p. 35, pl. 12, figs. 9-9a.

Retibrevitricolpites catatumbus Gonzalez, 1967, p. 36, pl. 12, figs. 8-8b.

Diagnosis: Retibrevitricolp(or)ate, small (13-20um), pore costate, reticulum uniform, lumina 0.5um in diameter, tectate, colpate/colporate.

Specimens: PIN 39+166, 8.5 x 111.7; PIN 39+166, 16 x 96

Retibrevitricolpites "santanderensis"

Fig. A-15, 38-39

Diagnosis: Retibrevitricolpate, small to mid-sized(22-30um), tectate 1um thick slightly decreasing near colpi, colpi costate, costae 3um wide, lumina of reticulum slightly increasing toward mesocolpia, 0.7-0.9um wide.

Specimens: PIN 39+166, 3.2 x 114.5; RE 143+120, 19.2 x 104

Discussion: *Retibrevitricolpites distinctus* Van Hoeken Klinkenberg, 1966 is smaller (13um), and lumina decrease toward mesocolpium, *Retibrevitricolpites triangulatus* Van Hoeken Klinkenberg, 1966 has a pore fastigiate, *Retibrevitricolpites retibolus* Leidelmeyer, 1966 is smaller (15-20um), and has a pore costate, *Retibrevitricolpites* "costatus" has a thicker exine (1.5um), lumina is finer (0.5um) and costae is narrower (2um).

Retibrevitricolpites triangulatus Van Hoeken Klinkenberg, 1966

Fig. A-16, 7-8

Diagnosis: Retibrevitricolporate, small-sized (17-26um), reticulate lumina decrease from equator to poles, colpi marginate, pore fastigiate, coarseness of sculpture is variable.

Specimens: UR 812, 10.6 x 92.9; PIN 32+0, 17.9 x 102.9

Genus *Retibrevitricolporites* Legoux, 1978

Retibrevitricolporites "grandis"

Fig. A-16, 9-10

Diagnosis: Retibrevitricolporate, mid-sized (26-50um), reticulate, lumina 0.5-0.9 wide, uniform, pore costate, when grain is degraded the sculpture appears scabrate or verrucate.

Specimens: PIN 0, 14.9 x 111.5 PIN 81+0, 21.4 x 81

Discussion: *Retibrevitricolporites* "speciosus" does not have an uniform lumina.

Retibrevitricolporites "speciosus"

Fig. A-16, 11-13

Diagnosis: Retibrevitricolporate, small to mid-sized (21-30um), reticulate lumina decrease from equatorial intercolpial areas to poles and colpi, colpi marginate, pore costate, inner spherical body, coarseness of sculpture is variable.

Specimens: N 354+120, 3.9 x 82.1

Discussion: *Retibrevitricolpites distinctus* Van Hoeken-Klinkenberg, 1966 is smaller (13um), and tectum thickens around colpi, *Retibrevitricolpites triangulatus* Van Hoeken-Klinkenberg, 1966 has a pore vestibulate, and a colpi marginate by thickening of tectum.

Genus *Retidiporites* Varma and Rawat, 1963

Retidiporites elongatus Sarmiento, 1992

Fig. A-16, 14-15

Diagnosis: Retidiporate, ellipsoid, mid-sized (30um), pore simple, reticulate unevenly, lumina rounded, angular or fusiform, decreasing toward pores, semitectate, wide columellae.

Specimens: N 110, 7.4 x 79.5

Retidiporites magdalenensis Van der Hammen and Garcia, 1966

Fig. A-16, 16

Diagnosis: Retidiporate, ellipsoid, mid-sized (27-40um), pore simple, evenly reticulate, tectate, coarseness of sculpture is correlated with grain size.

Specimens: N 4, 18.6 x 95

Retidiporites "poricostatus"

Fig. A-16, 17-19

Diagnosis: Retidiporate, rectangular, mid-sized (42um), pore costate, unevenly foveoreticulate, coarser near pores, one grain found

Specimens: N 45, 3.9 x 40.4

Discussion: *Retidiporites magdalenensis* Van der Hammen and Garcia, 1966 has a pore simple, and reticulum is evenly distributed, *Retidiporites elongatus* Sarmiento, 1992 has a lumina that decreases near pores.

Genus *Retimonocolpites* Pierce, 1961

Retimonocolpites "ovatum"

Fig. A-16, 20-21

Diagnosis: Monosulcate, mid-sized (32-60um), trapezoidal with angular borders (egg-like), micropitted densely, sometimes sparsely scabrate, colpus long with ends widely rounded, tectate, scabrate sculpturing is sometimes present.

Specimens: NA 59+90, 6.6 x 83.5

Discussion: *Retimonocolpites regio* Van der Hammen and Garcia, 1966 has an ellipsoidal shape, has a margo, and sulcus end is pointed. *Retimonocolpites splendidus* Gonzalez 1967 is globular to ellipsoid, and exine is thicker (2.5um).

Retimonocolpites regio Van der Hammen and Garcia, 1966

Fig. A-16, 22-23

Diagnosis: Monosulcate, mid-sized (30-53um), micropitted, prolate, sulcus long and slightly marginate, tectate, exine thin, lumina 0.4-0.8um wide, margo sometimes is indistinct.

Specimens: N 4, 7.6 x 85.3

Genus *Retipollenites* Gonzalez, 1967

Retipollenites "baculatus"

Fig. A-16, 24-25

Diagnosis: Inaperturate, mid-sized (40um), tectum 4um thick, reticulate, lumina 4-8um wide, muri 1.5um wide, nexine densely baculate, 1um high, one grain found.

Specimens: N 18, 14 x 82.7

Discussion: *Spirosyncolpites spiralis* Gonzalez, 1967 has a scabrate nexine, *Retipollenites confusus* Gonzalez, 1967 does not have a nexine densely baculate.

Retipollenites "magnus"

Fig. A-16, 26-28

Diagnosis: Inaperturate, large-sized(100um), very thick tectum 8.5um, nexine micropitted, reticulate, simplicolumellate, very sparse columellae supporting the tectum, lumina 8-13um wide, muri 3um wide, one grain found

Specimens: N 114, 12.3 x 110.5

Discussion: *Spirosyncolpites spiralis* Gonzalez, 1967 is smaller and nexine is scabrate, *Retipollenites confusus* Gonzalez, 1967 is smaller (48um), and exine is thinner (3um, reticulum only).

Genus *Retistephanocolpites* Leidelmeyer, 1966

Retistephanocolpites angeli Leidelmeyer, 1966

Fig. A-16, 29-30

Diagnosis: Retistephanocolpate, mid-sized (45-55um), colpi short, costate, reticulum uniform, lumina 1-1.5um wide.

Specimens: N 27, 20.3 x 101.2

Retistephanocolpites "fossulatus"

Fig. A-17, 1-3

Diagnosis: Retistephanocolpate, mid-sized (30-55um), polygonal-obtuse-convex in polar view, colpi very short, indistinct, sculpture reticulate-foveolate at poles, fossulate at equator, exine thick, 6-8 colpate.

Specimens: PIN 35+90, 15 x 94 PIN 42+100, 5.4 x 92.8

Discussion: *Retistephanocolpites angeli* Leidelmeyer, 1966 has longer colpi, *Retistephanocolpites williamsi* Germeraad *et al.*, 1968 has a spongy exine, *Retistephanocolporites festivus* Gonzalez, 1967 has a protruding costa, and lumina is uniform (0.8um), *Retistephanocolpites finalis* Gonzalez, 1967 has a thinner tectum (2.5um), and lumina uniform (1.2um wide).

Retistephanocolpites "gradatum"

Fig. A-17, 4-5

Diagnosis: Retistephanocolpate, mid-sized (40um), lumina decrease gradually from equator (1um) toward poles (<0.5um), colpi costate.

Specimens: PIN 42+100, 20 x 110

Discussion: *Retistephanocolpites angeli* Leidelmeyer, 1966 has an uniform lumina (1-1.5um), *Retistephanocolpites williamsi* Germeraad *et al.*, 1968 has an spongy exine, *Retistephanocolporites festivus* Gonzalez, 1967 has a protruding costa, and lumina is smaller and uniform.

Retistephanocolpites "inciertus"

Fig. A-17, 6-7

Diagnosis: Retistephanocolpate, mid-sized (30um), colpi short, costate, lumina large (2-4um), angular, and uniform, one grain found.

Specimens: PIN 52+110, 22.3 x 80.3

Discussion: *Retistephanocolpites angeli* Leidelmeyer, 1966 has a smaller lumina (1-1.5um), *Retistephanocolpites williamsi* Germeraad *et al.*, 1968 has an spongy exine,

Retistephanocolporites festivus Gonzalez, 1967 has a protruding costa, and lumina is smaller and uniform.

Genus *Retistephanocolporites* Van der Hammen and Wijmstra, 1964

Retistephanocolporites festivus Gonzalez, 1967

Fig. A-17, 8-9

Diagnosis: Retistephanocolporate, mid-sized (26-50um), colpi very short, pore costate, costa thick and protruding, reticulate lumina<1.0 um, tectate, thin exine, 4-6 colporate, a few grains are 3-colporate, lumen of reticulum 0.7-1.0um in diameter, pores size 2-6um.

Specimens: PIN 42+100, 19.7 x 98.2; PIN 35+90, 7.6 x 111.4

Retistephanocolporites "fossulatus"

Fig. A-17, 10-13

Diagnosis: Retistephanocolporate, mid-sized (24-28um), colpi very short, pore indistinct, costa non-protruding, reticulate/foveolate/fossulate on same grain, tectate 1.5um thick, sculpturing is variable in same grain.

Specimens: PIN 28+0, 7.8 x 97.7

Discussion: *Retistephanocolporites festivus* Gonzalez, 1967 has a protruding costa, and lumina is smaller and uniform (0.8um), *Retistephanocolpites finalis* Gonzalez, 1967 has a thicker tectum (2.5um), a larger size (41-51um), and uniform lumina (1.2um wide).

Genus *Retistephanoporites* Gonzalez, 1967

Retistephanoporites angelicus Gonzalez, 1967

Fig. A-17, 14-15

Diagnosis: Retistephanoporate, mid-sized (30um), pores simple, reticula uniform, circular, dense, lumina 0.9-1um, 5-6 colpate

Specimens: PIN 55+50, 11 x 113.5

Retistephanoporites "crassiexinatus"

Fig. A-17, 16-17

Diagnosis: Retistephanoporate, hexagonal, mid-sized (37um), exine semitectate thick (3.6um), nexine thick, one grain found

Specimens: PIN 28+0, 5.2 x 85.6

Discussion: *Retistephanoporites angelicus* Gonzalez, 1967 has a thinner exine (1.7um), and ectexine is thicker than endexine, *Retistephanoporites* "minutipori" has smaller pores (1um), and thinner exine (1.5um).

Retistephanoporites "minutipori"

Fig. A-17, 18-19

Diagnosis: Retistephanoporate, mid-sized (26-35um), pores small, costate, reticula uniform, dense, lumina 0.9-1um.

Specimens: PIN 28+0, 11.4 x 98.1

Discussion: *Retistephanoporites angelicus* Gonzalez, 1967 has pores simple. *Retistephanoporites* "crassiexinatus" has a thicker exine (3.5um).

Retistephanoporites "regaloi"

Fig. A-17, 20-21

Diagnosis: Retistephanoporate, mid-sized (30um), pores lolongate, costate, reticula dense, lumina 0.4um, exine thin 0.8um, columellae indistinct, one grain found

Specimens: La Paz 712m, 12.7x 107.9

Discussion: *Retistephanoporites angelicus* Gonzalez, 1967 has a exine thicker (1.7um), *Retistephanoporites* "crassiexinatus" has a exine thicker (3.5um), and lumina wider (1-1.5um).

Genus *Retisyncolporites* Gonzalez, 1967

Retisyncolporites angularis Gonzalez, 1967

Fig. A-17, 22

Diagnosis: Syncolporate, mimd-sized (40-46um), fossulate-low verrucate, thick exine (3.5um).

Specimens: RE 241+40, 21.8 x 87.2; RE 251+30, 5.5 x 100

Retisyncolporites "complicatus"

Fig. A-17, 23-24

Diagnosis: Retisyncolporate, mid-sized (30um), colpi marginate by thinning of exine, poricostate, apocolpial field absent, tectate 1.2 um thick, lumina of reticula <0.7um decreasing toward colpi, one grain found, degradation may give the impression of baculae in the mesocolpium as columellae loose tectum cover.

Specimens: PIN 81+0, 3.1 x 95.1

Discussion: *Syncolporites marginatus* Van Hoeken Klinkenberg, 1964 has fossulae perpendicular to colpi and it is circular in polar view.

Psilasyncolporites aureus Gonzalez, 1967 has a reticula that diminishes toward poles, and colpi is simple.

Retisyncolporites "delicatus"

Fig. A-17, 25-27

Diagnosis: Retisyncolporate, mid-sized (40-50um), marginate, pore large, simple, lumina decrease toward colpi margo, margo width 2-4um.

Specimens: PIN 12, 5 x 100.9; N 354+120, 11.6 x 85.3

Discussion: *Syncolporites marginatus* Van Hoeken Klinkenberg, 1964 is smaller (20um), poricostate, and has an uniform lumina, *Retisyncolporites angularis* Gonzalez, 1967 is fossulate-low verrucate, and has a thick exine (3.5um).

Genus *Retitricolpites* Van der Hammen, 1956 ex Van der Hammen and Wijmstra, 1964

Retitricolpites absolutus Gonzalez, 1967

Fig. A-18, 1-2

Diagnosis: Tricolpate, mid-sized (27um), subprolate, colpi short, costate, exine thick, tectate, psilate at equator passing transitional to foveolate-reticulate at poles, one grain found.

Specimens: PIN 55+30, 4.8 x 104.4

Retitricolpites antonii Gonzalez, 1967

Fig. A-18, 3-4

Diagnosis: Retitricolpate, mid-sized (26um), prolate, colpi long, simple, columellae barely distinct, tectate 1.5um thick, one grain found.

Specimens: PIN 32+0, 14.2 x 107.9

Retitricolpites "baculensis"

Fig. A-18, 5-8

Diagnosis: Retitricolpate, mid to large-sized (50-70um), tectate exine, 7.8um thick, long columellae, reticulate, usually tectum is lacking given appearance of very dense baculae, when tectum is present muri 1.5 um wide, lumina 5-8 wide, younger grains have a more defined reticulum with muri being present over most of the surface

Specimens: PIN 12, 6.5 x 106; N 74, 13,8 x 82.1; PIN 47+100, 13.2 x 83.2; PIN 81+0, 18,1 X 111,6

Discussion: *Spirosyncolpites spiralis* Gonzalez, 1967 has a well defined muri, a lower columellae density, and shorter columellae, *Retitricolpites saturum* Gonzalez, 1967 is smaller (40-47um), exine is thinner (3.2um), and lumina narrower (3.2um).

Retitricolpites clarensis Gonzalez, 1967

Fig. A-18, 9

Diagnosis: Retitricolpate; mid-sized (29-40um); finely reticulated (lumina 0.7-1um); colpi simple, long; tectate, columella distinct, sculpturing looks fossulate when grain is deteriorated.

Specimens: PIN 32+0, 12.4 x 97.6; N 265, 18.2 x 95.6; N 354+120M 7,5 X 89

Retitricolpites "costatus"

Fig. A-18, 10-11

Diagnosis: Retitricolpate; mid-sized (40um); micropitted densely (lumina <0.5um); colpi costate, columellae indistinct, one grain found.

Specimens: PIN 71+0, 9.7 x 99.2

Discussion: *Retitricolpites clarensis* Gonzalez, 1967 has an uniform exine and colpi is simple, *Retitricolpites belskii* (Belski *et al.* 1968) Sarmiento, 1992 has colpi interangular, a dark stain in polar area, and is smaller (~25um), *Retitricolpites* "marginocostatus" is marginate, and columellae is distinct.

Retitricolpites florentinus Gonzalez, 1967

Fig. A-18, 12-13

Diagnosis: Retitricolpate, mid-sized (40um), prolate, lumina 1-1.5um wide at equator decreasing to 0.5um gradually toward poles, one grain found.

Specimens: PIN 81+0, 9.1 x 89.1

Retitricolpites magnus Gonzalez, 1967

Fig. A-18, 14-15

Diagnosis: Retitricolpate, mid-sized (38-55um), lumina 3-4m wide, uniform, dense, muri

thin, simplicolumellate, colpi simple, long.

Specimens: PIN 32+0, 19.4 x 88.8

Retitricolpites "marginocostatus"

Fig. A-18, 16-17

Diagnosis: Retitricolpate; mid-sized (40um); densely micropitted (lumina <0.6um); colpi costate and marginate by shortening of columellae. one grain found.

Specimens: PIN 19+60, 11.9 x 113.7

Discussion: *Retitricolpites clarensis* Gonzalez, 1967 has an uniform exine and colpi is simple, *Retitricolpites belskii* (Belski *et al.* 1968) Sarmiento, 1992 has colpi interangular, a dark stain in polar area, and is smaller (~25um), *Retitricolpites* "costatus" is not marginate, and columellae is indistinct.

Retitricolpites "peculiaris"

Fig. A-18, 18-22

Diagnosis: Retitricolpate, mid-sized (38-55um), lumina large 6-10 m wide, muri thin, simplicolumellate, sometimes the muri is reticulate itself, colpi costate, short, complex intrareticulation is not always present.

Specimens: NA 46, 17 x 101.6; NA 46, 22 x 91; NA 46, 11.5 x 96.5

Discussion: *Retitricolpites marginatus* Van Hoeken Klinkenberg, 1966 has a smaller lumina (3.5um) that decreases along colpi, *Retitricolporites elegans* Wijmstra, 1971 has pores, and lumina decreases toward poles and near colpi; *Retitriporites* "amplireticulatus" is porate, and muri is slightly wider (1um), *Retitrescolpites catenatus* Pocknall and Nichols, 1996 (1996)is smaller (24-33um), has a longer colpi extending almost to poles, exine thinner (2um), other species of *Retitrescolpites* Sah, 1967 have an etipila(ria)te exine.

Retitricolpites perforatus Gonzalez, 1967

Fig. A-18, 23-25

Diagnosis: Retitricolpate, mid-sized (32um), reticulate-foveolate-fossulate in same grain, lumina <1um wide, 0.8-2um long, one grain found.

Specimens: RE 67+120, 14.5 x 109.5

Retitricolpites "protoclarensis"

Fig. A-19, 1-2

Diagnosis: Tricolpate; mid-sized (22-45um), circular, densely micropitted (lumina 0.4-0.7um); colpi simple, long, ecto/endoexinous; tectate, thin exine (<1um), columella indistinct

Specimens: N 120, 15 x 91.8

Discussion: *Retitricolpites clarensis* Gonzalez, 1967 is very similar but exine is thicker (1um), columella distinct, and lumina wider (0.7-1um in diameter).

Retitricolpites saturum Gonzalez, 1967

Fig. A-19, 3-4

Diagnosis: Retitricolpate, mid-sized (40-47um), lumina 3m wide, muri thin, undulating, columellae long (1.5um), sometimes tectum is absent in some parts of the grain seeming baculate.

Specimens: N 110, 7.3 x 887

Genus *Retitricolporites* Van der Hammen 1956 ex Van der Hammen and Wijmstra 1964

Retitricolporites "arctus"

Fig. A-19, 5-6

Diagnosis: Tricolporate, mid-sized (30-36um), prolate, micropittted at the poles, psilate at equator, ectocolpi costate, pore simple.

Specimens: PIN 42+100, 8.3 x 78.5

Discussion: Unique sculpturing in the *Retitricolporites* group.

Retitricolporites cienagensis Dueñas, 1980

Fig. A-19, 7

Diagnosis: Tricolporate, mid-sized (26-31um), ectocolpi marginate, endopores costate, lumina decrease toward margo where is psilate, exine thickness decreases toward colpi. margo width 4-1.5um

Specimens: PIN 35+90, 21 x 110

Retitricolporites "delicatus"

Fig. A-19, 8-9

Diagnosis: Tricolporate, mid-sized (28-35 um), spherical, pore costate, lalongate, conspicuous, colpi simple, thin, mid-sized, tectate thin, columella indistinct, micropitted."

Specimens: PIN 52+110, 11 x 91.5

Discussion: *Psilatricolporites maculosus* Regali *et al.*, 1974 has a continuous equatorial costae, *Psilatricolporites* "spongiosus" is subprolate, equatorial costa is very thick, and tectum spongy, *Psilatricolporites transversalis* Dueñas, 1980 has a colpi shorter and indistinct, pores are protruding, it is psilate and subspherical, *Retitricolporites* "poricostatus" has a larger lumina (0.7 um), columellae distinct, and a shape triangular-obtuse-convex.

Retitricolporites "distinctus"

Fig. A-19, 10-11

Diagnosis: Retitricolporate, mid-sized (35-41um), zonocolpate costate, meridional colpi very short and indistinct, lumina decreasing from equator to poles, distinctiveness of pores is variable.

Specimens: N 120, 18.2 x 85.2

Discussion: *Retitricolporites costatus* Leidelmeyer, 1966 is smaller (25um) and has an uniform very fine reticula.

Retitricolporites "grandis"

Fig. A-19, 12-13

Diagnosis: Retitricolporate, mid-sized (40-52um), colpi marginate, pores costate, fastigiate, thin tectate, columellae indistinct, micropitted.

Specimens: RE 67+120, 12.8 x 113

Discussion: *Retitricolporites costatus* Leidelmeyer, 1966 is smaller (25um) and has an uniform very fine reticula, *Psilatricolporites marginatus* Van der Kaars, 1983 has a marginate colpi, a smaller size (19-27um), and lack vestibula, *Retitricolporites* "vestibulatus" is smaller (23-40um), has a colpi simple, and columellae distinct.

Retitricolporites guianensis Van der Hammen and Wymstra, 1964

Fig. A-19, 14-15

Diagnosis: Retitricolporate, mid-sized (28-40um), loose-meshed reticulate 3-4um wide, diminishing toward colpi, regularly distributed columellae, smaller grains with smaller lumina, some tricolpate.

Specimens: PIN 32+0, 9.8 x 91

Retitricolporites hispidus Van der Hammen and Wymstra, 1964

Fig. A-19, 16

Diagnosis: Retitricolporate, mid-sized (22-36um), prolate, lumina <0.8um, pores and colpi costate, exine thick (2um).

Specimens: PIN 39+166, 17.6 x 105

Retitricolporites "insolitus"

Fig. A-19, 17-18

Diagnosis: Retitricolporate, large-sized (60um), colpi long, simple, pores indistinct, tectate, nexine thick (2um), reticulate lumina 3.5-4.5um wide, angular, uniform, one grain found

Specimens: PIN 81+0, 18.2 x 79.5

Discussion: *Retitricolporites quadrosi* Regali *et al.*, 1974 has a colpi costate, and it is reticulate-foveolate.

Retitricolporites irregularis Van der Hammen and Wymstra, 1964

Fig. A-19, 19

Diagnosis: Retitricolporate, mid-sized (23-5um), circular, reticulum muricostate, colpi and pores costate, coarseness of ornamentation is variable.

Specimens: N 354+120, 7.3 x 103.8

Retitricolporites "longicolpis"

Fig. A-19, 20-21

Diagnosis: Retitricolporate, mid-sized (40um), colpi long, pores circular, distinct, large (6um), nexine very thick (2um), sexine thin, columella distinct, thinning near colpi, fine reticulate, one grain found.

Specimens: PIN 55+30, 7.3 x 89.5

Discussion: *Retitricolporites* "pachynexinatus" has a thicker nexine (3um) that diminish near colpi, and pores are indistinct.

Retitricolporites "marginatus"

Fig. A-19, 22-24

Diagnosis: Retitricolporate, mid-sized (43-50um), ectocolpi marginate, lumina large (2um) in intercolpial equator decreasing toward margo where is micropitted and toward poles where 1um wide.

Specimens: PIN 28+0, 6 x 106.5

Discussion: *Retitricolporites saskiae* Gonzalez, 1967 has a reticulum finer toward equatorial area, *Retitricolporites ellipticus* Van Hoeken Klinkenberg, 1966 has a colpi costate, *Retitricolporites quadrosi* Regali *et al.*, 1974 has a costate colpi, and exine is thicker (3um), *Retitricolporites perpusillus* Regali *et al.*, 1974 is smaller (28-36um), has a lumina intercolpate wider (3-4um) that abruptly decrease near colpi margin.

Retitricolporites mariposus Leidelmeyer, 1966

Fig. A-20, 1-3

Diagnosis: Tricolporate, mid-sized (28um), triangular-acute-convex, micropittted, ectocolpi intruding, pore slightly costate, exine thinner near colpi.

Specimens: N 265, 13.7 x 109.1

Retitricolporites medius Gonzalez, 1967

Fig. A-20, 4

Diagnosis: Tricolporate, small to mid-sized (19-30um), subprolate, micropittted, ectocolpi intruding, pore simple, columellae distinct, exine 1-1.5um.

Specimens: N 354+120, 7.5 x 109.3 PIN 32+0, 19 x 91.5

Retitricolporites "minutus"

Fig. A-20, 5-6

Diagnosis: Tricolporate, small to mid-sized (21-30um), subprolate, micropittted, ectocolpi costate, pore simple, columellae barely distinct.

Specimens: PIN 39+166, 6.9 x 110.5

Discussion: *Retitricolporites medius* Gonzalez ,1967 has a colpi simple, *Retitricolporites squarrosus* Van der Hammen and Wymstra, 1964 has a thicker exine (2um), distinct columella, and lumina wider (0.7um).

Retitricolporites "pachynexinatus"

Fig. A-20, 7-8

Diagnosis: Retitricolporate, mid-sized (25-36um), nexine very thick (3um) thinning near colpi, sexine thin, columella indistinct, fine reticulate.

Specimens: PIN 42+100, 15.8 x 98.4

Discussion: *Retitricolporites* "longicolis" has a thinner nexine (2um) that do not diminish near colpi, pores distinct, and lumina is uniform.

Retitricolporites "poricostatus"

Fig. A-20, 9-11

Diagnosis: Tricolporate, small-sized (20-25um), reticula fine, ectocolpi simple, long, pore costate, columellae distinct.

Specimens: N 354+120, 11.6 x 107

Discussion: *Retitricolporites costatus* Leidelmeyer, 1966 has very short colpi, *Retitricolpites cienagensis* Dueñas, 1980 is colpimarginate, *Retitricolporites mariposus* Leidelmeyer, 1966 has columellae decreasing in thickness toward colpi, lumina is smaller (<0.5um), exine is thicker (1.5um), and costa is narrower (1um).

Retitricolporites squarrosus Van der Hammen and Wymstra, 1964

Fig. A-20, 12-13

Diagnosis: Tricolporate, small-sized (26um), subprolate, reticulate fine, lumina 0.7um, ectocolpi costate, pore simple, exine thick (2um).

Specimens: PIN 35+90, 12.5 x 104.1

Retitricolporites "tropicalis"

Fig. A-20, 14-17

Diagnosis: Retitricolporate, mid-sized (24-30um), colpi costate, costae reduced at equator, pores indistinct, micropitted, columellae reduced near colpi, distinctiviness of lalongate pores is variable.

Specimens: N 74, 7.2 X 106.5 N 74, 6.5 X 85

Discussion: *Retitricolporites crassicostatus* Van Hoeken Klinkenberg, 1966 has a costa uniform, and columella thickness is constant.

Retitricolporites "vestibulatus"

Fig. A-20, 18-20

Diagnosis: Retitricolporate, mid-sized (23-40um), pore conspicuously costate and fastigiate, sculpture reticulate fine to psilate.

Specimens: N 174, 6.4 x 83.8

Discussion: *Retitricolporites costatus* Leidelmeyer, 1966 is smaller (25um) and has an uniform very fine reticula, *Psilatricolporites marginatus* Van der Kaars, 1983 has a marginate colpi, a smaller size (19-27um), and lack vestibula.

Genus *Retitriporites* Ramanujam, 1966

Retitriporites "amplireticulatus"

Fig. A-20, 21-23

Diagnosis: Triangular-obtuse-convex, mid-sized (40um), triporate, pores indistinct, with a large simplicolumellate reticulum and a thick semitectate exine (2.8um) with distinct columellae, and muri 1um wide, only one specimen.

Specimens: N 110, 6.9 X 97.3

Discussion: *Retitriporites variabilis* Muller, 1968 has indistinct columellae which tops are fused to a single structureless narrow band, and muri <1um wide, *Retitricolpites* "peculiaris" is colpate, and muri is slightly thinner (0.8um).

Retitriporites "annulatus"

Fig. A-20, 24-25

Diagnosis: Retitriporate, triangular-obtuse-convex, mid-sized (38um), annuli distinct, reticula uniform, semitectate, 1.5um thick., one grain found

Specimens: N 27, 20 x 96.5

Discussion: *Proteacidites dehaani* Germeraad *et al.*, 1968 has a larger reticulum, coarser in interporate fields, and a continuous costa, *Proteacidites* "pseudocostatus" has a triangular-acute straight shape, and costae segmented, *Retitriporites tilburgii* Gonzalez, 1967 is smaller (26um), and annuli is narrower (1um).

Retitriporites "pachyexinatus"

Fig. A-20, 26-27

Diagnosis: Retitriporate, small-sized (25um), circular, tectate 1.8 um thick, poricostate, pores lolongate, one grain found

Specimens: PIN 42+100, 4.9 x 93.1

Discussion: *Retitriporites tilburgii* Gonzalez, 1967 has a thinner exine (1.2um), and smaller circular pores (2um).

Retitriporites "peculiaris"

Fig. A-20, 28-29

Diagnosis: Retitriporate, mid-sized (40um), semitectate, 2um thick, sexine diminishing toward pores, annulate, reticula irregular, lumina diminishing from poles toward pores, one grain found

Specimens: PIN 35+90, 5.6 x 84.5

Discussion: *Retitriporites typicus* Gonzalez, 1967 is smaller (27-33um), spheroidal, and lumina size diminish toward equator.

Retitriporites "perforatus"

Fig. A-20, 30-31

Diagnosis: Retitriporate, pore costate and protruding, micropitted at equator, foveolate/fossulate at poles, tectate, exine thick (2um), one grain found

Specimens: PIN 52+110, 5 x 87.5

Discussion: *Retitriporites simplex* Van der Kaars 1983 has a lumina uniform and pore simple, *Retitriporites typicus* Gonzalez, 1967 has a larger lumina (1.2um) that gradually decrease toward equator, sometimes sculptural elements are not fused.

Retitriporites "poricostatus"

Fig. A-20, 32-33

Diagnosis: Retitriporate, mid-sized (25-35um), costae distinct, slightly protruding, 3um thick, 4um wide, reticula uniform, angular, 1.5-2 wide, simplicolumellate.

Specimens: PIN 71+0, 18.1 x 82

Discussion: *Retitriporites federicii* Gonzalez, 1967 has a lumina large (3um), thicker exine (2.3um), and muri broader (2um).

Genus *Rugotricolporites* Gonzalez, 1967

Rugotricolporites felix Gonzalez, 1967

Fig. A-21, 1-2

Diagnosis: Retitricolporate, mid-sized (31um), prolate, rugulate, rugulae short, curved, colpi marginate.

Specimens: PIN 28+0, 17.7 x 81.5

Genus *Scabrastephanocolpites* Van der Hammen and Garcia, 1966

Scabrastephanocolpites "casanaris"

Fig. A-21, 3-4

Diagnosis: Scabrastephanocolporate, mid-sized (40um), colpi short, marginate, atectate 0.5um thick, one grain found.

Specimens: N 265, 20 x 102

Discussion: *Scabrastephanocolpites vanegensis* Van der Hammen and Garcia, 1966 has a larger colpi (14/37um) and margo is less distinct, *Scabrastephanocolpites scabratus* Van der Hammen and Garcia, 1966 is tectate, *Scabrastephanocolpites guadensis* (Van der Hammen, 1954) Sarmiento, 1992 has a thicker exine (2um).

Genus *Scabratricolporites* Van der Hammen, 1956 ex Poche and Schuler, 1976

Scabratricolporites "amplocolpatus"

Fig. A-21, 5-7

Diagnosis: Scabratricolporate, prolate, mid-sized (32-44um), atectate, colpi long, costate, pores lalongate, costate, porecosta 2-3um wide, surrounding partially or entirely the pore.

Specimens: UR 812, 10.5 x 91.5; UR 812, 14.2 x 103.9; UR 531+120, 10.5 x 82.8

Discussion: *Scabratricolporites platanensis* Dueñas, 1980 has colpi and pores simple, *Scabratricolporites* "tomassoi" is tectate and costae of pores is narrower (1um).

Scabratricolporites "tomassoi"

Fig. A-21, 8-9

Diagnosis: Scabratricolporate, small-sized (20-25um), tectate, colpi long, costate, pores lalongate, costate.

Specimens: PIN 42+100, 11.9 x 103

Discussion: *Scabratricolporites platanensis* Dueñas, 1980 has colpi and pores simple, *Scabratricolporites* "amplicolpatus" is atectate and costae of pores is wider (3um).

Genus *Scabratriporites* Van der Hammen 1956 ex Van Hoeken Klinkenberg, 1964

Scabratriporites "bellus"

Fig. A-21, 10-11

Diagnosis: Scabratriporate, mid-sized (36um), annulate, annuli 3-4um wide/2um thick, atectate (0.5um), scabrae <0.5um wide/high, one grain found

Specimens: RE 251+30, 5.1 x 98.2

Discussion: *Scabratriporites simpliformis* Van Hoeken Klinkenberg, 1966 is smaller (21um), annuli is thinner (1.2um), and amb is triangular-convex, *Cricotriporites* "macropori" has a wider circular pore (5-9um) and annuli is thinner (1um).

Genus *Spinizonocolpites* Muller, 1968

Spinizonocolpites "brevibaculatus"

Fig. A-21, 12-14

Diagnosis: Zonocolpate, mid-sized (32-50um), tectate (1-2um thick), tectum finely reticulate, lumina <1um, baculate, baculae 3.5-6um long, 7-12um apart, rounded or slightly pointed tips, straight or slightly curved, (reworked?).

Specimens: UR 531+120, 21.5 x 97; UR 531+120, 14 x 108.5

Discussion: *Spinizonocolpites baculatus* Muller, 1968 is practically identical but has consistently longer baculae (7-13um), *Spinizonocolpites* "pluribaculatus" has a thicker exine (3um), tectum micropitted, and baculae more densely distributed (2-4um).

Spinizonocolpites "breviechinatus"

Fig. A-21, 15-17

Diagnosis: Spinizonocolpate, mid to large-sized (40-65um), tectate (1 um thick), tectum micropitted, echinate, spines 2-4um long, 1-2um wide, 3-5um apart, cylindrical to subconical, , spines height is relatively constant within same grain.

Specimens: N 110, 14.8 x 110.2 N 74, 8.2 x 95

Discussion: *Spinizonocolpites echinatus* Muller, 1968 is very similar but spines are significateiy larger (5-7um), wider, more spaced from each other, and conical with lower part slightly expanded, *Spinizonocolpites* "grandis" has wider spines (3-4um wide), longer (4-5um high), and conical.

Spinizonocolpites "grandis"

Fig. A-21, 18-20

Diagnosis: Spinizonocolpate, large-sized (70-85um), tectate (1 um thick), tectum finely reticulate, echinate, spines 4-5um long, 3-4um wide, 5-10um apart, conical, spines height and shape are relatively constant within same grain.

Specimens: PIN 12, 11.4 x 111.2

Discussion: *Spinizonocolpites echinatus* Muller, 1968 is smaller (33-43) and has spines larger (5-7um), *Spinizonocolpites* "breviechinatus" has narrower spines (1-2um wide), shorter (2-4um high), and subconical to cylindrical.

Spinizonocolpites "pachyexinatus"

Fig. A-21, 21-22

Diagnosis: Spinizonocolpate, large-sized (70-80um), tectate thick (3-5um thick), tectum micropitted to finely reticulate, lumina <0.7um, echinate, spines 7-10 long, 10-20 um apart, often slightly expanded at the base, spines hollow to massive, psilate to micropitted, tectum micropitted to finely reticulated.

Specimens: N 174, 13 x 108

Discussion: *Spinizonocolpites echinatus* Muller, 1968 is similar but exine is thinner (2um) and spines shorter (5-7um).

Spinizonocolpites "pluribaculatus"

Fig. A-22, 1-2

Diagnosis: Zonocolpate, mid-sized (55um), tectate thick(3um thick), columellae barely distinct, tectum micropitted, baculae 4-6 long, 2-6 um apart, one grain found, baculae shape variable is same grain. (reworked?)

Specimens: UR 761, 17.5 x 92.3

Discussion: *Spinizonocolpites baculatus* Muller, 1968 is similar but exine is thinner (1-2um) and has longer baculae (7-13um), *Spinizonocolpites* "brevibaculatus" has a thinner tectum (1-2um), tectum is finely reticulate, and baculae is more scattered (7-12um apart).

Genus *Spirosyncolpites* Gonzalez, 1967, emend. Legoux, 1978

Spirosyncolpites spiralis Gonzalez, 1967

Fig. A-22, 3-5

Spirosyncolpites spiralis Gonzalez, 1967, p. 45, pl. 16, figs. 1-1c.

Retitricolpites amapaensis Regali *et al.*, 1974, p 280, pl. 17, fig. 4.

Diagnosis: Retitricolpate, mid to large-sized (32-85um), colpi often indistinct, exine tectate 9um thick, reticulate, lumina 8um-14um wide, muri 1.2um wide, simplibaculate, nexine scabrate.

Specimens: PIN 81+0, 17.9 x 104.5; PIN 32+0, 19 x 101.8

Discussion: The holotype of *Retritricolpites amapaensis* Regali *et al.,* 1974 was observed and correspond to this species.

Genus *Striatricolpites* Van der Hammen, 1956 ex Gonzalez, 1967

Striatricolpites catatumbus Gonzalez, 1967

Fig. A-22, 6-7

Diagnosis: Striatricolp(or)ate, prolate, mid-sized (37-53um), colpi simple, long, intruding, pore indistinct, tectum thick, 2.5um thick, muri subparallel to slightly anastomosing, 1um high, 1um apart, 1-1.5um wide, coarseness of wall is variable as well as presence of pores.

Specimens: PIN 66+80, 15.6 X 108.5

Striatricolpites minor Wijmstra, 1971

Fig. A-22, 8

Diagnosis: Striatricolpate, subprolate, small-sized (15-18um), colpi simple, long, pores absent or indistinct, tectate, exine thin, 0.8um thick, muri subparallel to colpi, 0.3um high, <0.5um apart, <0.5um wide. one grain found

Specimens: N 120, 11.9 x 115.1

Striatricolpites "orinocus"

Fig. A-22, 9-10

Diagnosis: Striatricolpate, prolate, mid-sized (35-41um), colpi simple, long, tectum thin, exine 1um thick, muri parallel to colpi, 0.4um high, 0.5-0.7 um apart, 0.8um wide, tectum reticulate within striae.

Specimens: N 74, 5 x 96.6

Discussion: *Striatricolpites catatumbus* Gonzalez, 1967 has a thicker exine (3um) and wider muri (1-1.5um), *Striatricolpites semistriatus* Gonzalez, 1967 has muri bifurcating at the poles, *Striatricolpites saramacensis* Wijmstra, 1971 has a thicker exine (2-3um), *Striatricolporites tenuissimus* Dueñas 1980 has a colpi costate, *Striatricolporites agustinus* Gonzalez 1967 is smaller (19-23um), *Striatricolporites pimulis* Leidelmeyer, 1966 has a endopore annulate, and exine diminishes near colpi.

Striatricolpites "tenuistriatus"

Fig. A-22, 11-13

Diagnosis: Striatricol(por)ate, prolate, mid-sized (36-45um), colpi costate, long, pore, when present, lolongate and costate, striae and muri 0.5um wide, muri <0.5 high, meridionally elongated, exine thin, 0.8um thick, columella indistinct, a few grains are tricolporate.

Specimens: RE 143+120, 15.6 x 95.2; UR 812, 17.8 x 89.4

Discussion: *Striatricolpites catatumbus* Gonzalez, 1967 has a thicker exine (3um) and wider striae (1.5um), *Striatricolpites semistriatus* Gonzalez, 1967 has a thicker exine (1.5um) and striae bifurcate at the poles, *Striatricolpites saramacensis* Wijmstra, 1971 has a thicker exine (2-3um) and columellae distinct, *Striatricolporites tenuissimus* Dueñas, 1980 is reticulate within striae (lumina 0.5-0.8um wide), *Striatricolporites agustinus* Gonzalez, 1967 is smaller (19-23um).

Genus *Striatricolporites* Leidelmeyer, 1966

Striatricolporites "digitatus"

Fig. A-22, 14-15

Diagnosis: Striatricolporate, prolate, mid-sized (35um), colpi costate, long, pore indistinct, muri pattern resembles a finger print, exine tectate, 1um thick, columella distinct, one grain found.

Specimens: N 21+100, 16 x 101.9

Discussion: *Striatricolpites catatumbus* Gonzalez, 1967 has a thicker exine (3um), wider muri (1.5um), subparallel, *Striatricolpites semistriatus* Gonzalez, 1967 has muri bifurcating at the poles, *Striatricolpites saramacensis* Wijmstra, 1971 has a thicker exine (2-3um) and muri parallel, *Striatricolporites tenuissimus* Dueñas, 1980 is reticulate within striae (lumina 0.5-0.8um wide), *Striatricolporites agustinus* Gonzalez, 1967 is smaller (19-23um) and muri parallel, *Striatricolporites pimulis* Leidelmeyer, 1966 has a

endopore annulate, and exine is thinning near colpi, *Dactylopollis* Muller, 1968 is colpate, foveolate-reticulate in intercolpate equatorial areas and curved-striate along colpi and near poles.

Striatricolporites "reticulatus"

Fig. A-22, 16-17

Diagnosis: Striatricolpate, prolate, mid-sized (25-36um), colpi costate, pores costate lalongate, exine thick, 1.5-2um thick, striations very faint and randomly organized, overlying a tectum finely reticulate distinctiveness of costae of colpi is variable.

Specimens: N 149, 19 x 91

Discussion: *Striatricolpites catatumbus* Gonzalez, 1967 has a thicker exine (3um) and higher muri (1um), *Striatricolporites tenuissimus* Dueñas, 1980 has a thinner exine (1um) and pore simple, *Striatricolporites pimulis* Leidelmeyer, 1966 has a exine that diminishes near colpi, *Striatricolporites* "orinocus" has thinner exine (0.8um) and reticula is less uniform.

Genus *Syncolporites* Van der Hammen, 1954

Syncolporites lisamae Van der Hammen, 1954

Fig. A-22, 18-19

Diagnosis: Syncolporate, small-sized (16-21um), pore annulate, apocolpial field absent, scabrate, psilate in annuli zone, intectate (<0.5um thick), one grain.

Specimens: N 87, 11.4 x 84.1

Syncolporites marginatus Van Hoeken Klinkenberg, 1964

Fig. A-22, 20-21

Diagnosis: Retisyncolporate, small-sized (20um), colpi marginate, pore costate, lumina

0.7um, dense, uniform.

Specimens: RE 113, 11.5 x 109.4

Syncolporites "verrucatus"

Fig. A-22, 22-23

Diagnosis: Syncolporate, small-sized (17um), verrucate, verrucae 1-1.3um wide, 1um high, colpi simple, pores annulate, one grain found.

Specimens: N 174, 12.2 x 114

Discussion: *Syncolporites lisamae* Van der Hammen, 1954 is scabrate to microverrucate (<0.5um high).

Genus *Ulmoideipites* Anderson, 1960

Ulmoideipites krempii (Anderson, 1960) Elsik, 1968b

Fig. A-22, 24

Ulmoideipites krempii Anderson, 1960, p. 20, pl. 4, fig. 12; pl. 6, figs. 2-3,: pl. 10, fig. 8

Verrustephanoporites simplex Leidelmeyer, 1966, p. 55, pl. 3, fig. 10; pl. 4, fig. 2

Ulmoideipites krempii (Anderson, 1960) Elsik, 1968b, p. 608, pl. 17, figs 4-7.

Diagnosis: Stephanoporate, 3-5-porate, mid-sized (26-35um), annulate, arcuate (arci faint to distinct), verrucate, exine thin (0.8um), tectate, verrucate height is variable.

Specimens: N 149, 18.6 x 96.9

Genus *Verrustephanocolpites* Van der Hammen and Garcia, 1966

Verrustephanocolpites "rugulatus"

Fig. A-22, 25

Diagnosis: Stephanocolpate, mid-sized (34-38um), colpi short, surrounded by 2 ridges, 1.5-2.5um high, verrucate to rugulate, intectate, each pair of ridges can be 6um to 1um apart, mesocolpium and apocolpium sculpture from verrucate to rugulate.

Specimens: N 265, 18.2 x 109.2

Discussion: *Ctenolophonidites* Van Hoeken Klinkenberg, 1966 has endexinous thickenings fusing at the poles forming a ring, *Cristatricolpites analemae* Leidelmeyer, 1966 has a columellae distinct, and it is psilate.

Genus *Verrustephanoporites* Leidelmeyer, 1966

Verrustephanoporites "gemmatus"

Fig. A-22, 26-27

Diagnosis: Stephanoporate, mid-sized (29um), pore costate, lalongate, tectate, columellae indistinct, microverrucae densely, with scattered microgemmae, microbaculae, and microclavae, one grain found.

Specimens: PIN 52+110, 4.3 x 104

Discussion: *Gemmastephanoporites breviculus* Gonzalez, 1967 is larger (34-40um), gemmae is higher (1.1um) and wider (1.1-1.3um), and tectum is reticulate, *Verrutricolporites* "reticulatus" is larger (31-57um), has colpi very short, verrucae 1-1.5 wide/0.5 high, and densely micropitted, *Scabrastephanoporites* "lolongatus" has lolongate pores, and sculpture is shorter (<0.5um).

Genus *Verrutricolpites* Pierce, 1961

Verrutricolpites "irregularis"

Fig. A-22, 28-29

Diagnosis: Verrutricolpate, mid-sized (33um), colpi very long, marginate, margo protruding, verrucae rounded to angular, irregularly shaped, 0.5um high. one grain found

Specimens: PIN 81+0, 8.8 x 87.2

Discussion: *Verrutricolpites isolatus* Leidelmeyer, 1966 has a colpi simple and verrucae is higher (3-3.5um).

Genus *Verrutricolporites* Van der Hammen and Wijmstra 1964, emend. Legoux, 1978

Verrutricolporites "reticulatus"

Fig. A-22, 31-33

Diagnosis: Verrutriporate, mid-sized (31-57um), pore costate, large (4-10um wide), verrucae 1.5-2 wide/0.5-1um high, densely micropitted to finely reticulated, 3-4 colporate, colpi often lacking.

Specimens: PIN 66+80, 21.5 x 104; PIN 52+110, 10.5 x 98; PIN 81+0, 19 x 103; PIN 81+0, 7.6 x 105.5.

Discussion: *Gemmastephanoporites breviculus* Gonzalez, 1967 is gemmate.

Genus *Wilsonipites* Srivastava, 1969

Wilsonipites margocolpatus Muller *et al.*, 1987

Fig. A-22, 30

Diagnosis: Tricolporate, micropittted, mid-sized (30um), colpi very long, almost syncolpate, marginate.

Specimens: RE 132, 6.4 x 102.3

Genus *Zonocostites* Germeraad *et al.*, 1968

Zonocostites "minor"

Fig. A-22, 34-36

Diagnosis: Psilatricolporate, small-sized (12-15um), prolate to subprolate, equatorial aperture elongated to fused, costate, slightly fastigiate, micropitted, to almost psilate at equator, coarseness of structure and perforations at the poles are variable.

Specimens: PIN 52+110<10, 6.5 x 97.9; PIN 52+110<10, 8.4 x 92; PIN 52+110NO, 15.4 x 97.5

Discussion: *Zonocostites ramonae* Germeraad *et al.*, 1968 is very similar but consistently larger (16-19um) and subprolate to circular, *Zonocostites duquensis* Dueñas, 1980 has a clear reticulation.

DINOFLAGELLATE CYSTS

Phylum PYRRHOPHYTA Pascher, 1914

Class DINOPHYCEAE Fritsch, 1929

Order PERIDINIALES Haeckel, 1894

Genus *Achomosphaera* Evitt, 1963

Achomosphaera sp. A

Fig. A-23, 1-2

Diagnosis: *Spiniferites*-type with no septa connecting process bases, wall psilate, body spherical, processes gonal and intergonal bifurcating or trifurcating more than once.

Size (50-60um)

Specimens: PIN 12, 6.4 x 94

Discussion: This genus has a large intraspecific morphological variation.

Genus *Cordosphaeridium* Eisenack, 1963

Cordosphaeridium sp. A

Fig. A-23, 3-7

Diagnosis: *Cordosphaeridium*-type, processes intratabular, fibrous, open distally, wall finely reticulate, Size (60-100um).

Specimens: PIN 12, 10.5 x 102.5; PIN 12, 4 x 95.2 ;PIN 47+100, 20.6 x 95.7

Discussion: preservation of few cysts available preclude species assignment

Genus *Coronifera* Cookson and Eisenack, 1958

Coronifera sp. A

Fig. A-23, 8-9

Diagnosis: Skolochorate, with multiple nontabular processes closed distally and a single large antapical process open distally, one cyst found.

Specimens: N 174, 13.1 x 80

Discussion: preservation of cyst available precludes species assignment

Genus *Glaphyrocysta* Stover and Evitt, 1978

Glaphyrocysta sp. A

Fig. A-23, 10-12

Diagnosis: *Glaphyrocysta*-type, provess complexes with many branched stalks, joined by a simple, slender trabeculae, wall between processes finely reticulate, lumina <0.6um, two cysts found

Specimens: PIN 35+90, 18.4 x 104.3

Discussion: Large intraspecific variation in this genus.

Genus *Homotryblium* Davey and Williams, 1966

Homotryblium floripes (Deflandre and Cookson, 1955) Stover, 1975

Fig. A-23, 13-15

Diagnosis: Skolochorate, AP: A(3A)6P, processes long, intratabular, size (70-100um)

Specimens: PIN 28+0, 11.3 X 90.1

Genus *Hystrichosphaeridium* Deflandre, 1937

Hystrichosphaeridium sp. A

Fig. A-24, 1-5

Diagnosis: Skolochorate, processes intratabular, parasutural ridges, parasulcus and paracingulum indicated by processes, size (60-70um).

Specimens: PIN 28+0, 12 x 107; PIN 52+110, 20 x 80.8

Discussion: Unique in having a distinct parasutural ridges that defines a complete paratabulation. Also it shows a *Hystrichosphaeridium* species with sexiform hypocyst.

Genus *Lingulodinium* Wall, 1967

Lingulodinium cf. *sicula* (Drugg, 1970) Wall and Dale in Wall *et al.*, 1973

Fig. A-24, 6-7

Diagnosis: *Operculodinium*-type, processes nontabular, subconical, closing distally, acuminate to evexate, size (50-60um)

Specimens: PIN 35+90, 10.3 x 92.2 PIN 52+110, 15.7 x 103

Discussion: Cysts fit description of *L. siculum*, although archeophyle type could not be determined.

Genus *Nematosphaeropsis* Deflandre and Cookson, 1955

Nematosphaeropsis sp. A

Fig. A-24, 8-10

Diagnosis: Skolochorate, intermediate-sized, parasutural process tips connected by a network of ribbon-like trabeculae, size (60-90um).

Specimens: PIN 12, 18.6 x 82

Discussion: preservation of cyst available precludes species assignment

Genus *Polysphaeridium* Davey and Williams, 1966

Polysphaeridium sp. A

Fig. A-24, 11-12

Diagnosis: Skolochorate, AP: A(3A)6P, processes long, narrow, cylindrical and nontabular, size (55-68um)

Specimens: PIN 12, 6.1 x 114.9

Discussion: large intraspecific variation in this genus.

Genus *Senegalinium* Jain and Millepied, 1973

Senegalinium sp. A

Fig. A-24, 13-14

Diagnosis: Deflandrea-type, circumcavate, endophragm psilate, periphragm slightly scabrate with longitudinal folds <1um wide and high, distinct at cingulum and fading away toward apical area, size (50-80um)

Specimens: RE 67+120, 6 x 92.1

Discussion: reworked dinocyst?, *Senegalinium* is common in Late Cretaceous sediments of Colombia

Genus *Spiniferites* Mantell 1850

Spiniferites cf. *mirabilis* (Rossignol, 1964) Sarjeant, 1970

Fig. A-25, 1-2

Diagnosis: Spiniferites-type, bicavate, greatly expanded epi and hypopericoel, wall psilate, processes gonal and intergonal, one cyst found.

Specimens: UR 726, 9.8 x 107.3

Discussion: very similar to *S. mirabilis,* but archeophyle could not be determined.

Spiniferites sp. A

Fig. A-25, 3-4

Diagnosis: *Spiniferites*-like, 60um, with wall finely reticulate

Specimens: PIN 12, 17.8 x 98.9

Discussion: Large intraspecific variation in this genus.

Genus *Systematophora* Klement, 1960

Systematophora? sp. A

Fig. A-25, 5-6

Diagnosis: Proximochorate, processes 5-6um long, densely distributed, subconical to tapering, occasionally two or more processes joined at the base by a ridge seeming arcuate penitabular complexes, wall between processes finely reticulate, one cyst found

Specimens: PIN 28+0, 12.5 x 83.6

Discussion: The archeophyle type could not be determined, also it is not clear if the processes are grouped in arcuate penitabular complexes. This data would confirm its affinity to *Systematophora* Klement 1960.

INCERTAE SEDIS GROUP

Incertae sedis A

Fig. A-23, 16-17

Diagnosis: Rhombic psilate grain, with a thin wall that thickens at the vertices of the grain, thickness of the wall (0.7-1.2um), size (50-60um).

Specimens: PIN 42+100, 23 x 95.4

Discussion: Probably a type of Zygnemataceae, genus *Mougeotia*.

Figure A-1. Illustration of palynomorphs
Bar scale=10um for Figures A-1 to A-
prv=proximal view,dv=distal view, ev=equatorial view, pv=polar view, lv=lateral view
hf=high focus, mf=mid focus, lf=low focus

taxa	size	focus	view	slide	coordenates
1 *Baculatisporites* "irregularis"	28 x 25	hf	prv	PIN 75+160	4.6 x 85.5
2 *Baculatisporites* "irregularis"	28 x 25	mf	prv	PIN 75+160	4.6 x 85.5
3 *Baculatisporites* "irregularis"	28 x 25	lf	prv	PIN 75+160	4.6 x 85.5
4 *Baculatisporites* "soleus"	28 x 28	hf	prv	PIN 42+100	5.6 x 109.7
5 *Baculatisporites* "soleus"	28 x 28	mf	prv	PIN 42+100	5.6 x 109.7
6 *Baculatisporites* "soleus"	28 x 28	lf	prv	PIN 42+100	5.6 x 109.7
7 *Camarozonosporites* "inciertus"	27 x 27	hf	prv	UR 812	13.9 x 112.1
8 *Camarozonosporites* "inciertus"	27 x 27	mf	prv	UR 812	13.9 x 112.1
9 *Camarozonosporites* "inciertus"	27 x 27	lf	prv	UR 812	13.9 x 112.1
10 *Chomotriletes minor*	38 x 35	mf	prv	PIN 24+60	17.9 x 86.5
11 *Cicatricosisporites dorogensis*	47 x 44	hf	dv	PIN 28+0	8.1 x 88.5
12 *Cicatricosisporites dorogensis*	47 x 44	mf	dv	PIN 28+0	8.1 x 88.5
13 *Cicatricosisporites dorogensis*	47 x 44	lf	dv	PIN 28+0	8.1 x 88.5
14 *C. dorogensis subsp. minor forv. rugulatearis*	57 x 60	hf	dv	PIN 12	12 x 101.7
15 *C. dorogensis subsp. minor forv. rugulatearis*	57 x 60	mf	dv	PIN 12	12 x 101.7
16 *C. dorogensis subsp. minor forv. rugulatearis*	57 x 60	lf	dv	PIN 12	12 x 101.7
17 *Cicatricosisporites* "infrafoveolatus"	40 x 37	hf	dv	N 18	4 x 86.7
18 *Cicatricosisporites* "infrafoveolatus"	40 x 37	mf	dv	N 18	4 x 86.7
19 *Cicatricosisporites* "infrafoveolatus"	40 x 37	lf	dv	N 18	4 x 86.7
20 *Cicatricososporites* "decussatus"	57 x 34	hf	lv	PIN 55+30	5.4 x 92.3
21 *Cicatricososporites* "decussatus"	57 x 34	mf	lv	PIN 55+30	5.4 x 92 3
22 *Cicatricososporites* "decussatus"	57 x 34	lf	lv	PIN 55+30	5.4 x 92.3

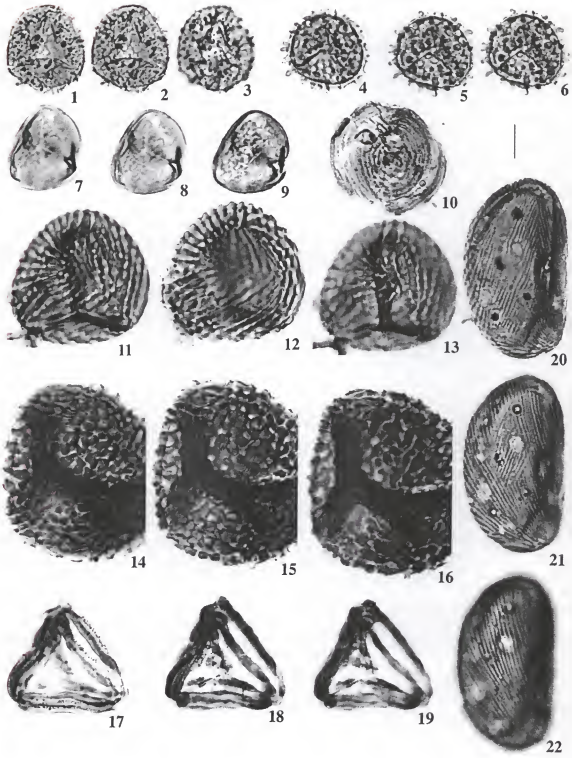

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Figure A-2. Illustration of palynomorphs
see key to labels in Figure A-1

	taxa	size	focus	view	slide	coordenates
1	*Cicatricososporites eocenicus*	55 x 35	hf	lv	PIN 52+110	6 x 102.6
2	*Cicatricososporites eocenicus*	60 x 40	hf	prv	PIN 28+0	17.6 x 110
3	*Clavatisporites mutisi*	31 x 25	hf	prv	N 87	14.1 x 85.5
4	*Clavatisporites mutisi*	31 x 25	mf	prv	N 87	14.1 x 85.5
5	*Echinatisporis* "brevispinosus"	30 x 26	hf	dv	PIN 81+0	9.4 x 84.5
6	*Echinatisporis* "brevispinosus"	30 x 26	mf	dv	PIN 81+0	9.4 x 84.5
7	*Echinatisporis* ? "cingulatus"	26 x 25	hf	dv	PIN 52+110	10.6 x 108.4
8	*Echinatisporis* ? "cingulatus"	26 x 25	mf	dv	PIN 52+110	10.6 x 108.4
9	*Echinatisporis* ? "cingulatus"	26 x 25	lf	dv	PIN 52+110	10.6 x 108.4
10	*Echinatisporis* "microechinatus"	27 x 25	hf	dv	PIN 19+60	19.1 x 88.2
11	*Echinatisporis* "microechinatus"	27 x 25	mf	dv	PIN 19+60	19.1 x 88.2
12	*Echinatisporis* "microechinatus"	27 x 25	lf	dv	PIN 19+60	19.1 x 88.2
13	*Echinatisporis* "obscurus"	34 x 34	hf	prv	N 110	21.2 x 92.1
14	*Echinatisporis* "obscurus"	34 x 34	mf	prv	N 110	21.2 x 92.1
15	*Echinatisporis* "obscurus"	30 x 25	lf	dv	N 110	3.6 x 91.9
16	*Echinatisporis* "portae"	24 x 20	hf	dv	PIN 28+0	5.2 x 87.1
17	*Echinatisporis* "portae"	24 x 20	mf	dv	PIN 28+0	5.2 x 87.1
18	*Echinatisporis* "portae"	24 x 20	lf	dv	PIN 28+0	5.2 x 87.1
19	*Foveotriletes* "fossulatus"	35 x 34	hf	prv	PIN 81+0	12.2 x 112.8
20	*Foveotriletes* "fossulatus"	35 x 34	lf	prv	PIN 81+0	12.2 x 112.8
21	*Foveotriletes* "fossulatus"	30 x 28	lf	dv	PIN 52+110	5 x 82.3
22	*Foveotriletes* "fossulatus"	30 x 28	mf	dv	PIN 52+110	5 x 82.3
23	*Foveotriletes margaritae*	40 x 36	hf	dv	PIN 63+20	17.6 x 106
24	*Foveotriletes margaritae*	40 x 36	mf	dv	PIN 63+20	17.6 x 106
25	*Ischyosporites* "problematicus"	38 x 32	hf	dv	N 265	12 x 114
26	*Ischyosporites* "problematicus"	38 x 32	mf	dv	N 265	12 x 114
27	*Ischyosporites* "problematicus"	38 x 32	lf	dv	N 265	12 x 114
28	*Ischyosporites* "problematicus"	40 x 40	lf	dv	N 110	13.9 x 85.6
29	*Kirchheimerisporites* "tenuiradiatus"	27 x 25	mf	prv	PIN 55+30	5.1 x 99.5
30	*Kirchheimerisporites* "tenuiradiatus"	27 x 25	lf	prv	PIN 55+30	5.1 x 99.5
31	*Laevigatosporites* "barcoi"	33 x 25	lf	lv	NA 46	10 x 108.1
32	*Laevigatosporites* "barcoi"	33 x 25	mf	lv	NA 46	10 x 108.1
33	*Laevigatosporites* "barcoi"	33 x 25	hf	lv	NA 46	10 x 108.1

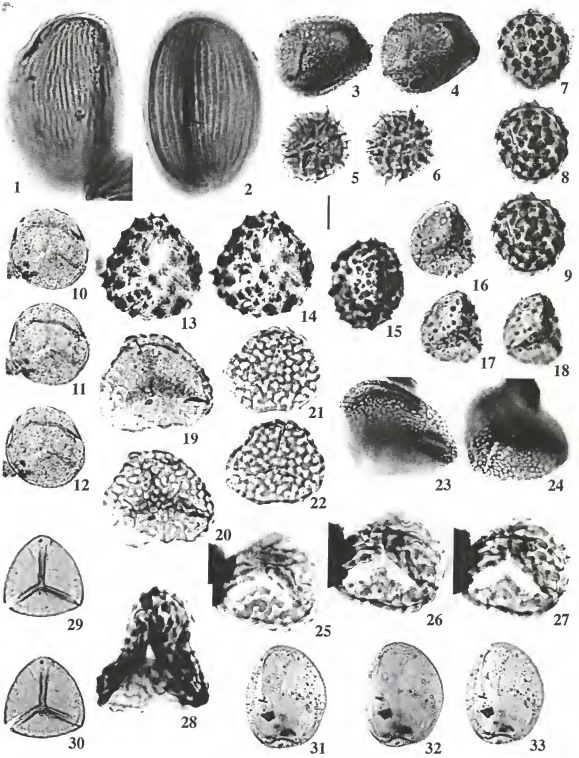
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Figure A-3. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Laevigatosporites* "tenuiexinatus"	50 x 36	hf	prv	PIN 28+0	15.5 x 93
2 *Laevigatosporites* "tenuiexinatus"	50 x 36	mf	prv	PIN 28+0	15.5 x 93
3 *Laevigatosporites* "tenuiexinatus"	50 x 36	lf	prv	PIN 28+0	15.5 x 93
4 *Laevigatosporites tibui*	41 x 35	mf	lv	N 21+100	6.6 x 91
5 *Microfoveolatosporis skottsbergii*	89 x 50	mf	lv	RE 67+120	6.8 x 92.3
6 *Microfoveolatosporis skottsbergii*	60 x 42	mf	lv	PIN 81+0	13.2 x 112
7 *Osmundacidites* "dispergatus"	30 x 26	hf	prv	N 18	7.9 x 105
8 *Osmundacidites* "dispergatus"	30 x 26	mf	prv	N 18	7.9 x 105
9 *Osmundacidites* "dispergatus"	30 x 26	lf	prv	N 18	7.9 x 105
10 *Osmundacidites* "minor"	26 x 25	hf	dv	PIN 63+20	14.8 x 87.4
11 *Osmundacidites* "minor"	26 x 25	mf	dv	PIN 63+20	14.8 x 87.4
12 *Osmundacidites* "minor"	26 x 25	lf	dv	PIN 63+20	14.8 x 87.4
13 *Polypodiaceoisporites* ? "fossulatus"	40 x 33	hf	dv	La Paz 886m	20.7 x 80.5
14 *Polypodiaceoisporites* ? "fossulatus"	40 x 33	mf	dv	La Paz 886m	20.7 x 80.5
15 *Polypodiaceoisporites* ? "fossulatus"	40 x 33	lf	dv	La Paz 886m	20.7 x 80.5
16 *Polypodiaceoisporites* ? "fossulatus"	38 x 37	hf	prv	PIN 52+110	6.7 x 112
17 *Polypodiisporites* "brevis"	26 x 24	hf	lv	UR 531+20	14.8 x 110.7
18 *Polypodiisporites* "brevis"	26 x 24	mf	lv	UR 531+20	14.8 x 110.7
19 *Polypodiisporites* "breviverrucatus"	50 x 35	hf	lv	La Paz 712m	17.6 x 106.5
20 *Polypodiisporites* "breviverrucatus"	50 x 35	mf	lv	La Paz 712m	17.6 x 106.5
21 *Polypodiisporites* "breviverrucatus"	50 x 35	lf	lv	La Paz 712m	17.6 x 106.5
22 *Polypodiisporites* "densus"	43 x 32	hf	prv	PIN 81+0	16.6 x 90
23 *Polypodiisporites* "densus"	43 x 32	mf	prv	PIN 81+0	16.6 x 90
24 *Polypodiisporites* "densus"	43 x 32	lf	prv	PIN 81+0	16.6 x 90

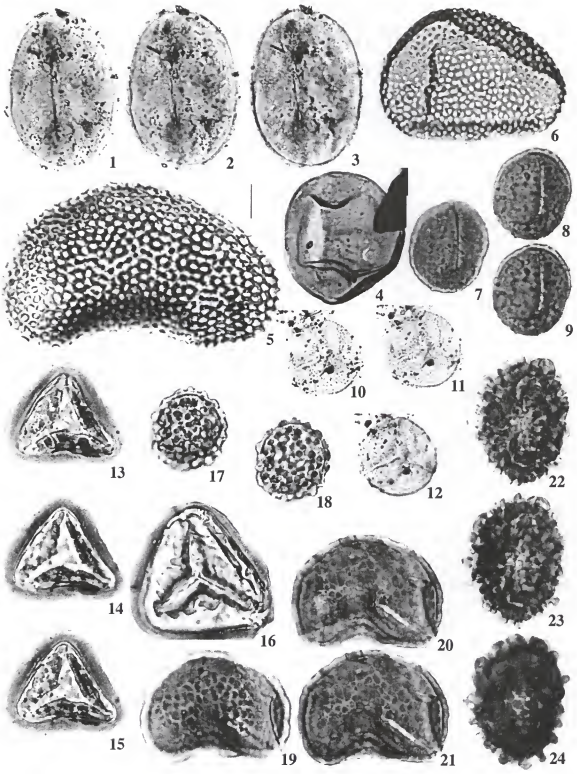
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Figure A-4. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Polypodiisporites* "echinatus"	40 x 30	hf	lv	N 74	15.5 x 108.5
2 *Polypodiisporites* "echinatus"	40 x 30	mf	lv	N 74	15.5 x 108.5
3 *Polypodiisporites* "echinatus"	40 x 30	lf	lv	N 74	15.5 x 108.5
4 *Polypodiisporites* "pachyexinatus"	45 x 30	hf	prv	N 174	8.2 x 92
5 *Polypodiisporites* "pachyexinatus"	45 x 30	mf	prv	N 174	8.2 x 92
6 *Polypodiisporites* "pachyexinatus"	45 x 30	lf	prv	N 174	8.2 x 92
7 *Polypodiisporites* "protousmensis"	50 x 30	mf	lv	N 21+100	11.6 x 98.8
8 *Polypodiisporites* "protousmensis"	50 x 30	lf	lv	N 21+100	11.6 x 98.8
9 *Polypodiisporites specious*	40 x 28	lf	lv	PIN 75+0	10.2 x 78.7
10 *Polypodiisporites specious*	40 x 28	mf	lv	PIN 75+0	10.2 x 78.7
11 Pteridacidites "cucutensis"	42 x 28	hf	dv	La Paz 712m	15 x 88.4
12 *Pteridacidites* "cucutensis"	40 x 32	hf	prv	La Paz 886m	8.2 x 78.3
13 *Pteridacidites* "cucutensis"	40 x 32	lf	prv	La Paz 886m	8.2 x 78.3
14 *Retitriletes* "enigmaticus"	60 x 50	hf	dv	PIN 66+80	5.5 x 84.2
15 *Retitriletes* "enigmaticus"	60 x 50	mf	dv	PIN 66+80	5.5 x 84.2
16 *Retitriletes* "enigmaticus"	60 x 50	lf	dv	PIN 66+80	5.5 x 84.2
17 *Tuberositriletes?* "inciertus"	26 x 26	hf	prv	N 354+120	15 x 107.7
18 *Tuberositriletes?* "inciertus"	26 x 26	mf	prv	N 354+120	15 x 107.7
19 *Tuberositriletes?* "inciertus"	26 x 26	lf	prv	N 354+120	15 x 107.7
20 *Tuberositriletes* "verrucatus"	30 x 27	hf	prv	PIN 12	10 x 94.9
21 *Tuberositriletes* "verrucatus"	30 x 27	mf	prv	PIN 12	10 x 94.9
22 *Tuberositriletes* "verrucatus"	30 x 27	lf	prv	PIN 12	10 x 94.9
23 *Zlivisporis blanensis*	55 x 52	mf	prv	N 120	18.3 x 95.4
24 *Zlivisporis blanensis*	55 x 52	exine	prv	N 120	18.3 x 95.4

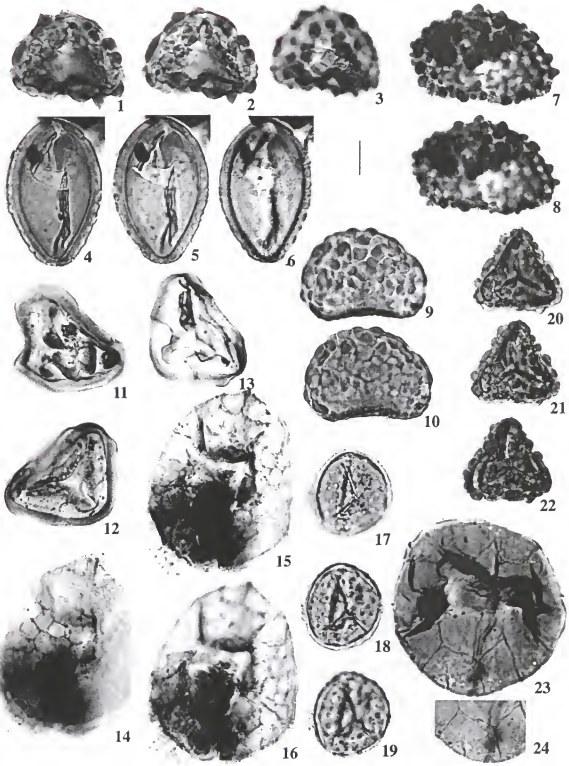
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Figure A-5. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Araucariaciates* "rugulatus"	66 x 40	lf	pv	N 149	11.3 x 92.5
2 *Araucariaciates* "rugulatus"	66 x 40	mf	pv	N 149	11.3 x 92.5
3 *Araucariaciates* "rugulatus"	66 x 40	hf	pv	N 149	11.3 x 92.5
4 *Araucariaciates* "scabratus"	56 x 43	hf	pv	N 74	14.5 x 104.7
5 *Araucariaciates* "scabratus"	56 x 43	mf	pv	N 74	14.5 x 104.7
6 *Ephedripites vanegensis*	38 x 17	mf	ev	NA 59+90	4.9 x 86.7
7 *Laevigatasporites* "laevigatus"	85 x 40	mf	pv	N 87	8 x 81.5
8 *Laevigatasporites* "laevigatus"	85 x 40	mf	pv	N 87	8 x 81.5
9 *Aglaoreidia?* "foveolatus"	42 x 25	hf	ev	N 45	14 x 111.2
10 *Aglaoreidia?* "foveolatus"	42 x 25	mf	ev	N 45	14 x 111.2
11 *Aglaoreidia?* "foveolatus"	42 x 25	lf	ev	N 45	14 x 111.2
12 *Anacolosidites ariani*	65 x 60	mf	pv	UR 531+120	14.6 x 114.6
13 *Anacolosidites ariani*	65 x 60	mf	pv	UR 531+120	14.6 x 114.6
14 *Baculamonocolpites* "angustus"	33 x 28	mf		UR 761	7.4 x 97.9
15 *Baculamonocolpites* "angustus"	33 x 28	lf		UR 761	7.4 x 97.9
16 *Baculamonocolpites* "bimodalis"	40 x 28	hf	pv	PIN 32	7 x 98
17 *Baculamonocolpites* "bimodalis"	40 x 28	mf	pv	PIN 32	7 x 98
18 *Baculamonocolpites* "bimodalis"	40 x 28	lf	pv	PIN 32	7 x 98
19 *Baculamonocolpites* "curubensis"	70 x 50	mf	ev	PIN 32+0	9.6 x 90.5
20 *Baculamonocolpites* "curubensis"	70 x 50	mf	ev	PIN 32+0	9.6 x 90.5
21 *Baculamonocolpites* "curubensis"	65 x 50	mf		PIN 52+110	6.6 x 97.1
22 *Baculamonocolpites* "curubensis"	65 x 50	mf		PIN 52+110	6.6 x 97.1
23 *Bacumorphomonocolpites tausae*	90 x 60	mf	pv	UR 502	11.8 x 97.1
24 *Bacumorphomonocolpites tausae*	90 x 60	mf	pv	UR 502	11.8 x 97.1
25 *Bacutriporites* "echinatus"	37 x 37	hf	pv	PIN 42+100	37 x 37
26 *Bacutriporites* "echinatus"	37 x 37	mf	pv	PIN 42+100	37 x 37

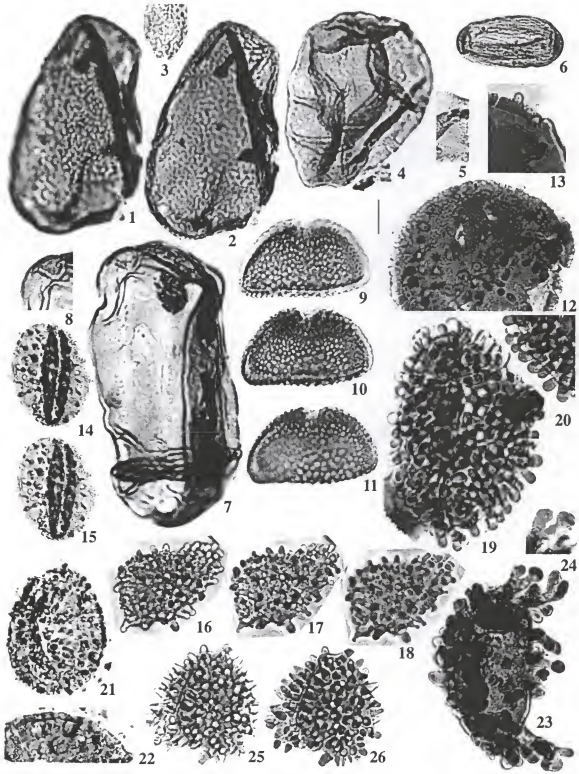
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Figure A-6. Illustration of palynomorphs
see key to labels in Figure A-1

	taxa	size	focus	view	slide	coordenates
1	*Bombacacidites annae*	40 x 40	mf	pv	N21+100	22.5 x 86.8
2	*Bombacacidites annae*	40 x 40	mf	pv	N21+100	22.5 x 86.8
3	*Bombacacidites annae*	35 x 38	hf	pv	NA 59+90	9.5 x 104.9
4	*Bombacacidites brevis*	29 x 27	mf	pv	PIN35+90	5.9 x 80
5	*Bombacacidites* "caldensis"	45 x 39	hmf	pv	NA46	7.9 x 84.5
6	*Bombacacidites* "caldensis"	45 x 39	lf	pv	NA46	7.9 x 84.5
7	*Bombacacidites* "caldensis"	45 x 39	mf	pv	NA46	7.9 x 84.5
8	*Bombacacidites* "dilcheroi"	35 x 36	hf	pv	RE67+120	21 x 99.3
9	*Bombacacidites* "dilcheroi"	35 x 36	mf	pv	RE67+120	21 x 99.3
10	*Bombacacidites* "dilcheroi"	35 x 36	lf	pv	RE67+120	21 x 99.3
11	*Bombacacidites* "etayoi"	30 x 33	hf	pv	N110	7.3 x 109.1
12	*Bombacacidites* "etayoi"	30 x 33	mf	pv	N110	7.3 x 109.1
13	*Bombacacidites* "fossureticulatus"	26 x 26	hf	pv	PIN 28+0	13 x 98.5
14	*Bombacacidites* "fossureticulatus"	26 x 26	mf	pv	PIN 28+0	13 x 98.5
15	*Bombacacidites foveoreticulatus*	35 x 31	hf	pv	PIN 81+0	11.8 x 98.1
16	*Bombacacidites foveoreticulatus*	35 x 31	mf	pv	PIN 81+0	11.8 x 98.1
17	*Bombacacidites* "gentryi"	40 x 39	hf	pv	PIN81+0	4.6 x 87
18	*Bombacacidites* "gentryi"	40 x 39	mf	pv	PIN81+0	4.6 x 87
19	*Bombacacidites* "gentryi"	40 x 39	mf	pv	PIN81+0	4.6 x 87
20	*Bombacacidites nacimientoensis*	40 x 40	hf	pv	PIN 28+0	18.6 x 100.3
21	*Bombacacidites nacimientoensis*	9 x 6	mf	pv	PIN 12+0	10.4 x 103
22	*Bombacacidites* "protociriloensis"	44 x 44	mf	pv	PIN81+0	8.2 x 115.2
23	*Bombacacidites* "protociriloensis"	44 x 44	mf	pv	PIN81+0	8.2 x 115.2
24	*Bombacacidites* "nissoides"	46 x 45	hf	pv	PIN 63+20	21 x 109.9
25	*Bombacacidites* "nissoides"	46 x 45	mf	pv	PIN 63+20	21 x 109.9
26	*Bombacacidites* "nissoides"	46 x 45	mf	pv	PIN 63+20	21 x 109.9

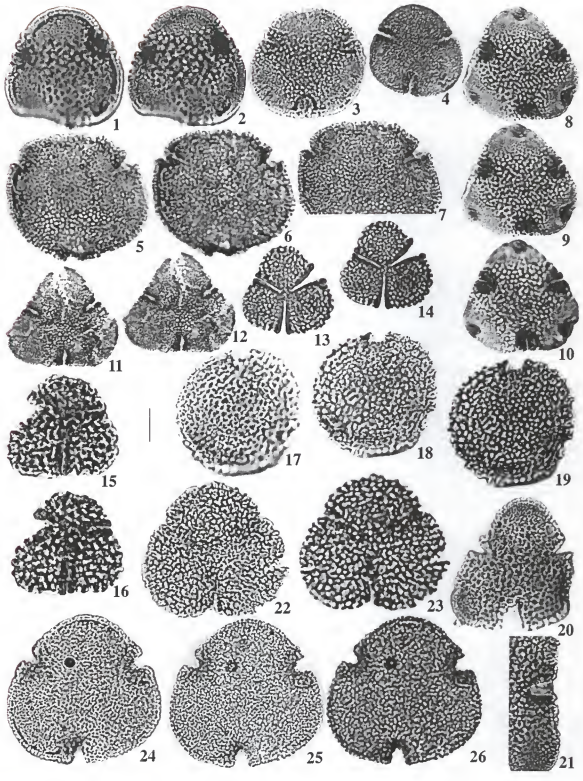
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Figure A-7. Illustration of palynomorphs
see key to labels in Figure A-1

	taxa		size	focus	view	slide	coordenates
1	*Bombacacidites*	"protofoveoreticulatus"	38 x 40	hf	pv	N27	20 x 89.3
2	*Bombacacidites*	"protofoveoreticulatus"	38 x 40	mf	pv	N27	20 x 89.3
3	*Bombacacidites*	"protofoveoreticulatus"	10 x 7	lf	pv	N110	18.3 x 95
4	*Bombacacidites*	"protofoveoreticulatus"	38 x 40	hf	pv	N27	8 x 98.9
5	*Bombacacidites*	"protofoveoreticulatus"	38 x 40	mf	pv	N27	8 x 98.9
6	*Bombacacidites*	"protofoveoreticulatus"	38 x 40	lf	pv	N27	8 x 98.9
7	*Bombacacidites*	"psilatus"	30 x 25	mf	pv	UR 781+20	16.7 x 90.8
8	*Bombacacidites*	"psilatus"	32 x 30	hf	pv	RE 67 + 120	18.5 x 110
9	*Bombacacidites*	"psilatus"	32 x 30	mf	pv	RE 67 + 120	18.5 x 110
10	*Bombacacidites*	"sabanensis"	39 x 37	hf	pv	PIN 81+0	14 x 91.4
11	*Bombacacidites*	"sabanensis"	39 x 37	mf	pv	PIN 81+0	14 x 91.4
12	*Bombacacidites*	"sabanensis"	50 x 45	mf	pv	PIN 52+110	3.3. x 113
13	*Bombacacidites*	"simplireticulensis"	52 x 50	mf	pv	PIN 28+0	12 x 95.5
14	*Bombacacidites*	"simplireticulensis"	52 x 50	lf	pv	PIN 28+0	12 x 95.5
15	*Bombacacidites soleaformis*		42 x 40	mf	pv	RE 132	15.5 x 93
16	*Bombacacidites soleaformis*		45 x 40	mf	pv	PIN 81+0	8.1 x 93.1
17	*Brevitricolpites*	"macroexinatus"	36 x 36	hf	pv	PIN 81+0	19.2 x 83.5
18	*Brevitricolpites*	"macroexinatus"	36 x 36	mf	pv	PIN 81+0	19.2 x 83.5
19	*Brevitricolpites*	"macroexinatus"	36 x 36	lf	pv	PIN 81+0	19.2 x 83.5
20	*Brevitricolpites*	"microechinatus"	41 x 38	hf	pv	N110	14.1 x 87.5
21	*Brevitricolpites*	"microechinatus"	41 x 38	mf	pv	N110	14.1 x 87.5
22	*Brevitricolpites*	"microechinatus"	41 x 38	mf	pv	N110	14.1 x 87.5
23	*Brevitricolpites*	"microechinatus"	8 x 6	colpus	pv	N110	4.1 x 87

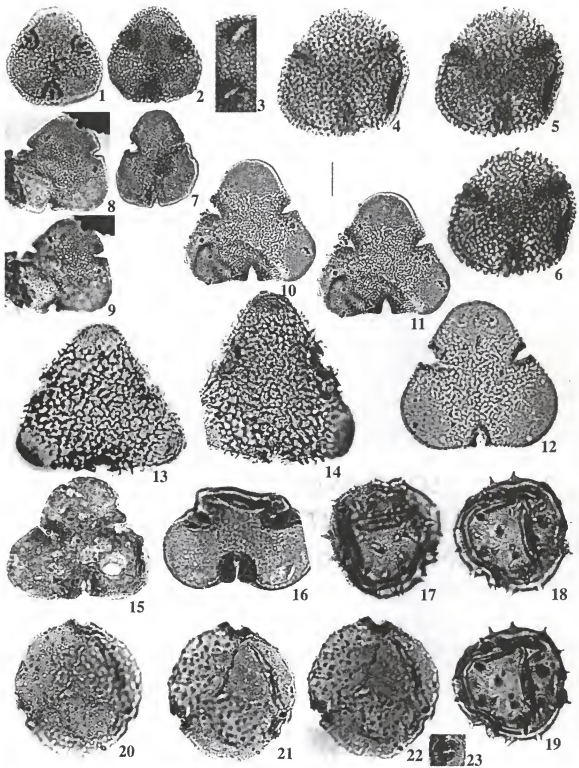
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Figure A-8. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Brevitricolpites* "scabratus"	35 x 34	hf	pv	N 149	20.4 x 102.8
2 *Brevitricolpites* "scabratus"	35 x 34	mf	pv	N 149	20.4 x 102.8
3 *Brevitricolpites* "scabratus"	35 x 34	mf	pv	N 149	20.4 x 102.8
4 *Clavamonocolpites* "macroclavatus"	42 x 35	hf	pv	PIN 71+0	7.5 x 83.8
5 *Clavamonocolpites* "macroclavatus"	42 x 35	mf	pv	PIN 71+0	7.5 x 83.8
6 *Clavamonocolpites* "macroclavatus"	42 x 35	lf	pv	PIN 71+0	7.5 x 83.8
7 *Clavatricolpites* "densoclavatus"	30 x 30	mf	pv	PIN 28+0	4.2 x 88.1
8 *Clavatricolpites* "densoclavatus"	30 x 30	mf	pv	PIN 28+0	4.2 x 88.1
9 *Clavatricolpites* "densoclavatus"	32 x 30	mf	ev	PIN 42+100	10.6 x 91
10 *Clavatricolpites* "densoclavatus"	37 x 37	mf	pv	PIN 52+110	15 x 111.6
11 *Colombipollis tropicalis*	52 x 45	mf	pv	N 74	10.2 x 88.8
12 *Cricotriporites guianensis*	30 x 24	hf	pv	RE 113	11.7 x 107.9
13 *Cricotriporites guianensis*	30 x 24	mf	pv	RE 113	11.7 x 107.9
14 *Cricotriporites* "macropori"	45 x 38	mf	pv	PIN 75+160	14.9 x 96.9
15 *Cricotriporites* "macropori"	45 x 36	mf	pv	RE 67+120	18 x 101.1
16 *Cricotriporites* "macropori"	35 x 35	mf	pv	PIN 55+30	13 x 105.7
17 *Cricotriporites* "macropori"	50 x 50	mf	pv	PIN 12	17 x 91
18 *Cricotriporites minutipori*	27 x 26	mf	pv	PIN 42+100	7.1 x 82.5
19 *Cricotriporites* "porielongatus"	30 x 28	hf	pv	PIN 63+20	10.9 x 110
20 *Cricotriporites* "porielongatus"	30 x 28	mf	pv	PIN 63+20	10.9 x 110
21 *Cricotriporites* "porielongatus"	35 x 39	mf	pv	PIN 55+30	16.3 x 113
22 *Crotoricolpites* cf. *annemariae*	48 x 46	mf	pv	UR 531+120	20.6 x 111
23 *Crotoricolpites* "protoannemarie"	40 x 40	hf	pv	N 18	13.3 x 97.3
24 *Crotoricolpites* "protoannemarie"	40 x 40	mf	pv	N 18	13.3 x 97.3
25 *Ctenolophonidites* "cruciatus"	45 x 50	mf	pv	PIN 28+0	18.4 x 111.5
26 *Ctenolophonidites* "cruciatus"	45 x 50	hf	pv	PIN 28+0	18.4 x 111.5
27 *Curvimonocolpites inornatus*	29 x 22	mf	pv	N4	13.2 x 101

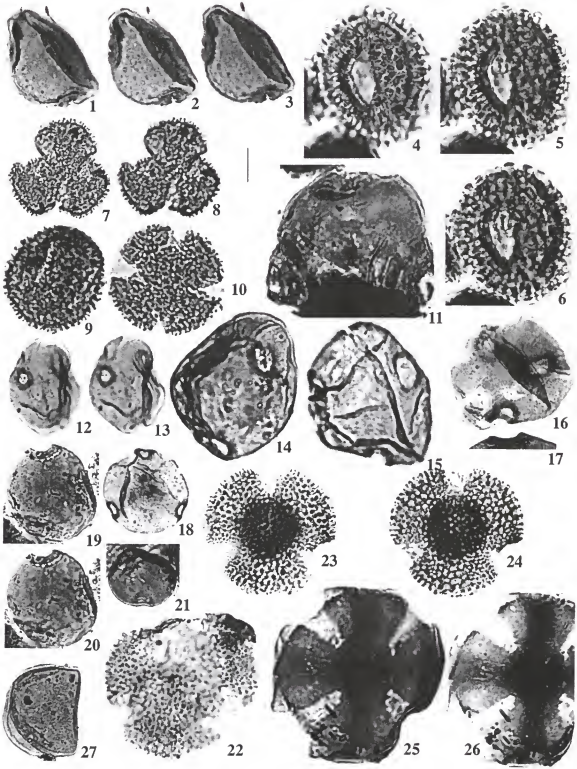
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Figure A-9. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Cyclusphaera* "scabratus"	31 x 23	hf	pv	N 354+120	5.9 x 89.2
2 *Cyclusphaera* "scabratus"	31 x 23	mf	pv	N 354+120	5.9 x 89.2
3 *Echimonocolpites* "tenuiechinatus"	30 x 26	hf	ev	N 74	11 x 103
4 *Echimonocolpites* "tenuiechinatus"	30 x 26	mf	ev	N 74	11 x 103
5 *Echipericolpites* "brevicolpatus"	27 x 26	hf	pv	N120	16.1 x 111.8
6 *Echipericolpites* "brevicolpatus"	27 x 26	mf	pv	N120	16.1 x 111.8
7 *Echipericolpites* "brevicolpatus"	27 x 26	lf	pv	N120	16.1 x 111.8
8 *Echiperiporites estelae*	46 x 35	mf	pv	PIN 28+0	5.2 x 80.5
9 *Echiperiporites estelae*	28 x 48	mf	pv	PIN 28+0	5.2 x 80.5
10 *Echiperiporites* "scabratus"	90 x 40	mf	pv	N 21+100	12.1 x 110
11 *Echiperiporites* "scabratus"	90 x 40	lf	pv	N 21+100	12.1 x 110
12 *Echiperiporites* "scabratus"	90 x 40	hf	pv	N 21+100	12.1 x 110
13 *Echiperiporites* "scabratus"	90 x 40	mf	pv	N 21+100	12.1 x 110
14 *Echitetracolpites* "echinatus"	40 x 40	hf	pv	PIN 28+0	18.9 x 105.5
15 *Echitetracolpites* "echinatus"	40 x 40	mf	pv	PIN 28+0	18.9 x 105.5
16 *Echitetracolpites* "tenuiexinatus"	45 x 39	hf	pv	PIN 52+100	5.8 x 90.9
17 *Echitetracolpites* "tenuiexinatus"	45 x 39	mf	pv	PIN 52+100	5.8 x 90.9
18 *Echitetracolpites* "tenuiexinatus"	34 x 35	mf	pv	PIN 42+100	18.3 x 85
19 *Echitricolpites* "linearis"	60 x 35	hf	ev	N110	4.1 x 82.3
20 *Echitricolpites* "linearis"	60 x 35	mf	ev	N110	4.1 x 82.3
21 *Echitricolpites* "linearis"	50 x 36	mf	ev	N120	15 x 109
22 *Echitriporites* "annulatus"	29 x 29	hf	pv	PIN 55+30	7 x 91.5
23 *Echitriporites* "annulatus"	45 x 42	mf	pv	PIN 47+100	7 x 91.5
24 *Echitriporites* "retiechinatus"	37 x 32	lf	pv	RE 113	7 x 88.6
25 *Echitriporites* "spissuexinatus"	33 x 49	hf	pv	N18	18.4 x 94.2
26 *Echitriporites* "spissuexinatus"	33 x 49	mf	pv	N18	18.4 x 94.2

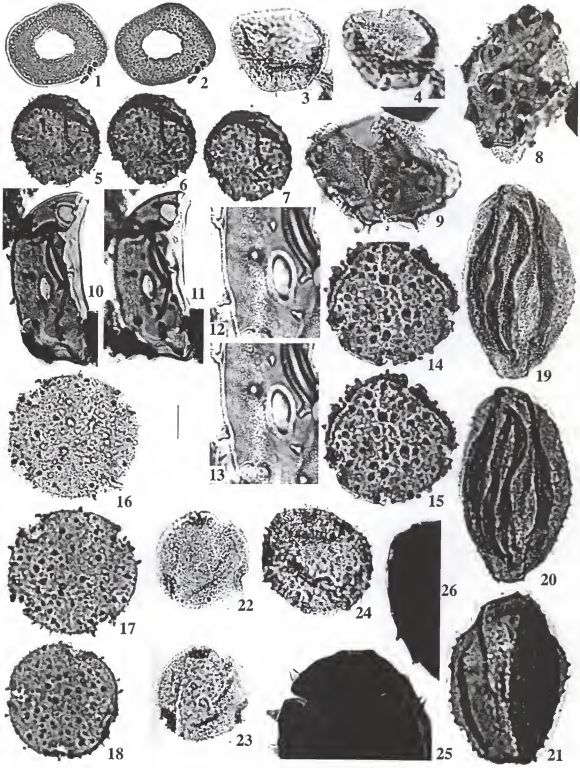
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Figure A-10. Illustration of palynomorphs
see key to labels in Figure A-1

	taxa	size	focus	view	slide	coordenates
1	*Echitriporites trianguliformis* var. "orbicularis"	22 x 21	hf	pv	PIN 12	7.3 X 83.5
2	*Echitriporites trianguliformis* var. "orbicularis"	22 x 21	mf	pv	PIN 12	7.3 X 83.5
3	*Echitriporites* "variabilis"	45 x 42	mf	pv	PIN 47+100	87.8 x 5.7
4	*Echitriporites* "variabilis"	45 x 42	mf	pv	PIN 47+100	87.8 x 5.7
5	*Echitriporites* "variabilis"	45 x 42	mf	pv	PIN 47+100	87.8 x 5.7
6	*Foveodiporites guinanesis*	36 x 23	hf	pv	N4	6.5 x 110.8
7	*Foveodiporites guinanesis*	36 x 23	mf	pv	N4	6.5 x 110.8
8	*Foveotricolpites* "costatus"	33 x 30	hf	pv	PIN 12	4 x 100.5
9	*Foveotricolpites* "costatus"	33 x 30	mf	pv	PIN 12	4 x 100.5
10	*Foveotricolpites* "costatus"	33 x 30	lf	pv	PIN 12	4 x 100.5
11	*Foveotricolpites perforatus*	35 x 29	mf	pv	N149	15.9 x 88.2
12	*Foveotricolpites perforatus*	35 x 29	lf	pv	N149	15.9 x 88.2
13	*Foveotricolporites* "brevicolpatus"	36 x 31	hf	pv	PIN 12	10 x 87
14	*Foveotricolporites* "brevicolpatus"	36 x 31	mf	pv	PIN 12	10 x 87
15	*Foveotricolporites* "brevicolpatus"	36 x 31	lf	pv	PIN 12	10 x 87
16	*Foveotricolporites* "fossulatus"	40 x 36	hf	ev	PIN 52+110	7.9 x 89.9
17	*Foveotricolporites* "fossulatus"	40 x 36	mf	ev	PIN 52+110	7.9 x 89.9
18	*Foveotricolporites* "marginatus"	30 x 27	lf	pv	PIN 52+110	17.9 x 82.5
19	*Foveotricolporites* "marginatus"	30 x 27	mf	pv	PIN 52+110	17.9 x 82.5
20	*Foveotricolporites* "microreticulatus"	30 x 25	hf	ev	N 354+120	14.9 x 96.5
21	*Foveotricolporites* "microreticulatus"	30 x 25	mf	ev	N 354+120	14.9 x 96.5
22	*Foveotricolporites* "poricostatus"	36 x 34	hf	pv	N 174	5.7 x 99
23	*Foveotricolporites* "poricostatus"	36 x 34	mf	pv	N 174	5.7 x 99
24	*Foveotricolporites* "rugulatus"	45 x 45	mf	pv	RE 251+30	18.1 x 88.7
25	*Foveotricolporites* "rugulatus"	40x 27	hf	ev	PIN 12	102.2 x 101
26	*Foveotriporites hammenii*	70 x 60	mf	pv	UR 812	13 x 96.5

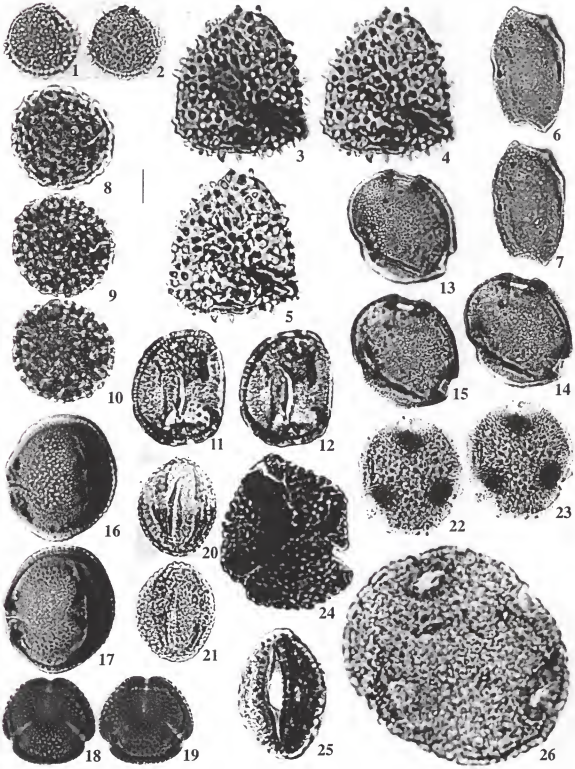
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Figure A-11. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Foveotriporites* "poricostatus"	50 x 40	hf	pv	PIN 81+0	16.3 x 105.5
2 *Foveotriporites* "poricostatus"	50 x 40	hf	pv	PIN 81+0	16.3 x 105.5
3 *Foveotriporites* "poricostatus"	50 x 40	mf	pv	PIN 81+0	16.3 x 105.5
4 *Foveotriporites* "poricostatus"	18 x 11	mf	pv	PIN 81+0	19.1 x 89.7
5 *Gemmamonocolpites* "ambigemmatus"	35 x 20	hf	ev	UR 812	21 x 84.4
6 *Gemmamonocolpites* "ambigemmatus"	35 x 20	mf	ev	UR 812	21 x 84.4
7 *Gemmamonocolpites gemmatus*	33 x 24	hf	pv	N 45	20 x 87.1
8 *Gemmamonocolpites gemmatus*	33 x 24	hf	pv	N 45	20 x 87.1
9 *Gemmamonocolpites* "mammiformis"	32 x 27	mf	pv	N 18	11.5 x 94
10 *Gemmamonocolpites* "mammiformis"	32 x 27	mf	pv	N 18	11.5 x 94
11 *Gemmamonocolpites* "megagemmatus"	42 x 34	hf	ev	PIN 52+110	18.8 x 87.1
12 *Gemmamonocolpites* "megagemmatus"	42 x 34	mf	ev	PIN 52+110	18.8 x 87.1
13 *Gemmamonocolpites* "megagemmatus"	42 x 34	lf	ev	PIN 52+110	18.8 x 87.1
14 *Gemmamonocolpites* "perfectus"	40 x 35	hf	ev	PIN 52+110	11 x 86.2
15 *Gemmamonocolpites* "perfectus"	40 x 35	hf	ev	PIN 52+110	11 x 86.2
16 *Jandufouria* "minor"	34 x 30	hf	pv	PIN 63+20	4.3 x 84
17 *Jandufouria* "minor"	34 x 30	mf	pv	PIN 63+20	4.3 x 84
18 *Jandufouria* "minor"	34 x 30	lf	pv	PIN 63+20	4.3 x 84
19 *Jussitriporites* "psilatus"	31 x 30	mf	pv	N 4	16.5 x 100
20 *Jussitriporites* "psilatus"	31 x 30	lf	pv	N 4	16.5 x 100
21 *Jussitriporites* "psilatus"	11 x 9	mf	pv	N 27	13.3 x 91.6
22 *Jussitriporites undulatus*	50 x 50	mf	pv	PIN 75+160	17.3 x 87.9
23 *Ladakhipollenites* "gemmatus"	28 x 28	hf	pv	RE 67+120	6.3 x 112.8
24 *Ladakhipollenites* "gemmatus"	28 x 28	mf	pv	RE 67+120	6.3 x 112.8
25 *Ladakhipollenites rubini*	11 x 11	hf	pv	PIN 42+100	4.6 x 103.2
26 *Ladakhipollenites rubini*	11 x 11	mf	pv	PIN 42+100	4.6 x 103.2
27 *Longapertites microfoveolatus*	53 x 25	hf	pv	N 87	18 x 81
28 *Longapertites microfoveolatus*	53 x 25	lf	pv	N 87	18 x 81
29 *Ladakhipollenites simplex*	32 x 20	mf	ev	RE 190+10	2.5 x 103.1

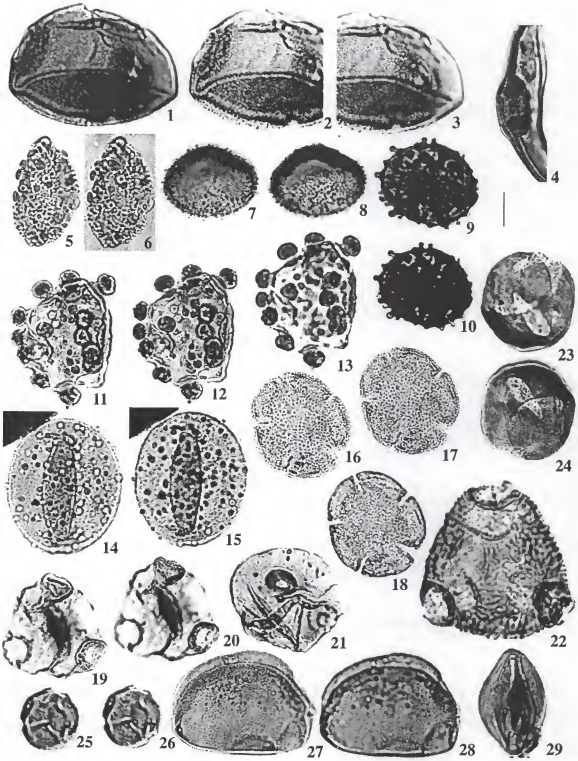
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Figure A-12. Illustration of palynomorphs6
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Longapertites* "ornatus"	45 x 32	hf	ev	PIN 52+110	2.9 x 99.9
2 *Longapertites* "ornatus"	45 x 32	mf	ev	PIN 52+110	2.9 x 99.9
3 *Longapertites* "ornatus"	45 x 32	lf	ev	PIN 52+110	2.9 x 99.9
4 *Longapertites proxapertitoides* var. *proxapertit*	48 x 25	mf	pv	N 265	13.4 x 93.5
5 *Longapertites proxapertitoides* var. *reticuloides*	44 x 27	mf	pv	N 265	8 x 84.3
6 *Luminidites* "colombianensis"	46 x 43	hf	prv	PIN 28+0	11.9 x 106.8
7 *Luminidites* "colombianensis"	46 x 43	mf	prv	PIN 28+0	11.9 x 106.8
8 *Luminidites* "colombianensis"	46 x 43	lf	prv	PIN 28+0	11.9 x 106.8
9 *Margocolporites vanwijhei*	40 x 40	hf	pv	RE 67+120	6.9 x 107
10 *Mauritiidites franciscoi* var. *franciscoi*	52 x 37	mf	pv	N 21 + 100	12 x 107.5
11 *Mauritiidites franciscoi* var. *franciscoi*	4 x 2	mf	pv	PIN 12	3.3 x 104
12 *Mauritiidites franciscoi* var. *franciscoi*	5 x 2	mf	pv	PIN 12	6.8 x 97.9
13 *Mauritiidites franciscoi* var. *franciscoi*	7 x 2.5	mf	pv	PIN 55+30	6.6 X 93
14 *Mauritiidites franciscoi* var. *franciscoi*	4 x 1.2	mf	pv	PIN 28+0	11.1 x 89
15 *Mauritiidites franciscoi* var. *franciscoi*	3.6 x 1.3	mf	pv	UR 761	13.1 X 78.8
16 *Mauritiidites franciscoi* var. *minutus*	30 x 26	mf	pv	N 354+120	7.6 x 80.5
17 *Mauritiidites franciscoi* var. *pachyexinatus*	60 x 55	mf	pv	PIN 39+166	20.4 x 99.3
18 *Momipites africanus*	23 x 29	mf	pv	N 18	8.9 x 87.1
19 *Momipites africanus*	23 x 29	mf	pv	N 18	8.9 x 87.1
20 *Momipites* "pachyexinatus"	41 x 39	mhf	pv	PIN 32+0	16.1 x 97.6
21 *Momipites* "pachyexinatus"	41 x 39	mmf	pv	PIN 32+0	16.1 x 97.6
22 *Monoporopollenites annulatus*	30 x 21	mf	ev	PIN 35+90	18.2 x 82.4
23 *Monoporopollenites annulatus*	36 x 30	hf	ev	N 354+120	10.5 X 83.7
24 *Nothofagidites* "huertasi"	26 x 24	hf	pv	PIN 66+80	10 x 95
25 *Nothofagidites* "huertasi"	26 x 24	mf	pv	PIN 66+80	10 x 95
26 *Nothofagidites* "lolongatus"	28 x 28	hf	pv	RE 241+40	18 x 92.7
27 *Nothofagidites* "lolongatus"	28 x 28	mf	pv	RE 241+40	18 x 92.7
28 *Perfotricolpites digitatus*	38 x 32	mf	pv	PIN 42+100	9.2 x 96.5

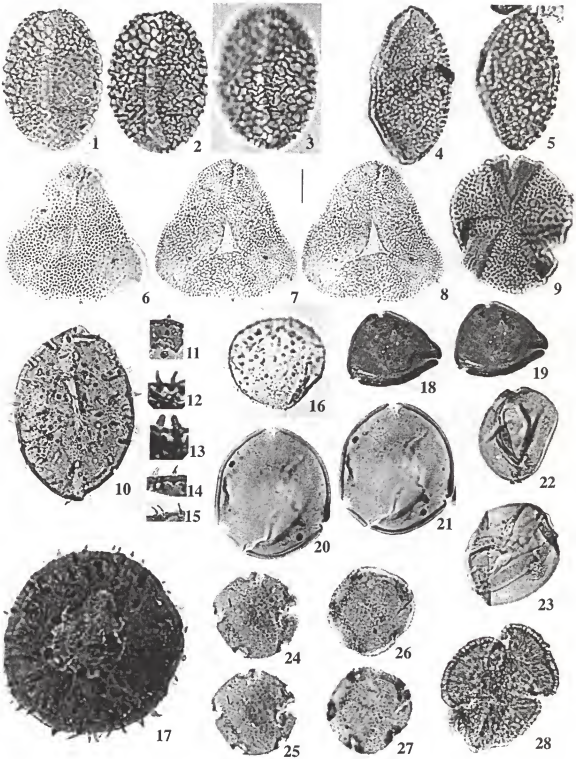
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Figure A-13. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Periretisyncolpites giganteus*	110 x 10(	mf	pv	La Paz 712m	10 x 81.2
2 *Periretisyncolpites* "inciertus"	120 x 90	hf	pv	N 18	7 x 97.6
3 *Periretisyncolpites* "inciertus"	120 x 90	mf	pv	N 18	7 x 97.6
4 *Periretisyncolpites* "inciertus"	54 x 34	hf	pv	N 18	7 x 97.6
5 *Periretisyncolpites* "inciertus"	54 x 34	mf	pv	N 18	7 x 97.6
6 *Perisyncolporites pokornyi*	32 x 30	mf	pv	RE 241+40	6 x 94.5
7 *Propylipollis* "pseudocostatus"	26 x 27	hf	pv	PIN 12	12.6 x 113
8 *Propylipollis* "pseudocostatus"	26 x 27	mf	pv	PIN 12	12.6 x 113
9 *Propylipollis* "pseudocostatus"	26 x 27	lf	pv	PIN 12	12.6 x 113
10 *Proxapertites cursus*	50 x 50	mf	pv	NA 59+90	12.8 x 108.5
11 *Proxapertites humbertoides*	95 x 90	mf	pv	UR 531+120	21 x 81.5
12 *Proxapertites humbertoides*	30 x 45	hf	pv	UR 531+120	21 x 81.5
13 *Proxapertites magnus*	84 X 80	mf	pv	RE 67+120	23 x 100
14 *Proxapertites magnus*	75 x 75	lf	pv	N 87	6.2 x 84.5
15 *Proxapertites operculatus*	42 x 42	mf	pv	NA 59+90	4.9 x 84.1
16 *Proxapertites psilatus*	28 x 26	mf	pv	PIN 42+100	5.5 x 100.5
17 *Proxapertites psilatus*	27 x 26	mf	pv	N 354+120	19.1 x 91.5
18 *Proxapertites verrucatus*	30 x 26	mf	pv	UR 531+120	14.8 x 102.9
19 *Proxapertites verrucatus*	27 x 25	hf	pv	UR 507	10.5 x 97.1
20 *Psilabrevitricolpites* "costatus"	30 x 30	mf	pv	N18	9.8 x 104
21 *Psilabrevitricolpites* "costatus"	30 x 30	mf	pv	N18	9.8 x 104
22 *Psilabrevitricolporites* "costatus"	36 x 40	hf	pv	PIN 42+100	12.3 x 112.5
23 *Psilabrevitricolporites* "costatus"	36 x 40	mf	pv	PIN 42+100	12.3 x 112.5
24 *Psilabrevitricolporites* "operculatus"	19 x 19	hf	pv	PIN 39+166	16 x 100.5
25 *Psilabrevitricolporites* "operculatus"	19 x 19	mf	pv	PIN 39+166	16 x 100.5

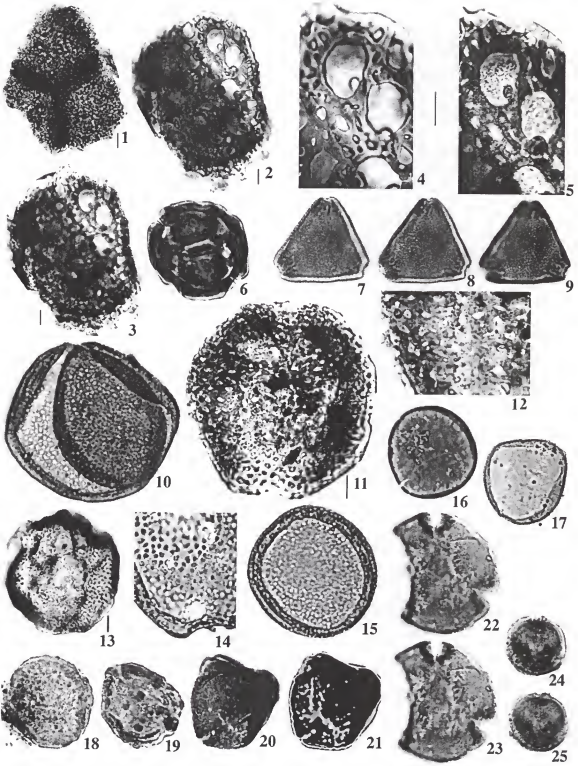
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Figure A-14. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Psilabrevitricolporites simpliformis*	26 x 26	hf	pv	N 21+100	12 x 107.1
2 *Psilabrevitricolporites simpliformis*	26 x 26	hf	pv	N 21+100	12 x 107.1
3 *Psilamonocolpites grandis*	51 x 40	mf	ev	N4	5.5 x 88.2
4 *Psilamonocolpites grandis*	51 x 40	lf	ev	N4	5.5 x 88.2
5 *Psilamonocolpites medius*	33 x 28	mf	ev	N 74	14 x 112.1
6 *Psilamonocolpites medius*	33 x 28	lf	ev	N 74	14 x 112.1
7 *Psilaperiporites* "enigmaticus"	22 x 20	hf	pv	NA -2	16.8 x 91.5
8 *Psilaperiporites* "enigmaticus"	22 x 20	mf	pv	NA -2	16.8 x 91.5
9 *Psilaperiporites* "pachyexinatus"	26 x 26	hf	pv	PIN 71	15 x 107
10 *Psilaperiporites* "pachyexinatus"	26 x 26	mf	pv	PIN 71	15 x 107
11 *Psilaperiporites* "pauciporatus"	32 x 29	hf	pv	PIN 12	13.5 x 87.2
12 *Psilaperiporites* "pauciporatus"	32 x 29	mf	pv	PIN 12	13.5 x 87.2
13 *Psilaperiporites* "pauciporatus"	32 x 29	lf	pv	PIN 12	13.5 x 87.2
14 *Psilastephanocolpites* "marginatus"	53 x 50	mf	pv	PIN 81+0	15 X 105
15 *Psilastephanocolpites* "marginatus"	53 x 50	hf	pv	PIN 81+0	15 X 105
16 *Psilastephanocolpites* "marginatus"	14 x 12	mf	pv	PIN 81+0	15 X 105
17 *Psilastephanocolpites* "punctum"	26 x 26	hf	pv	PIN 42+100	15.5 x 110
18 *Psilastephanocolpites* "punctum"	26 x 26	mf	pv	PIN 42+100	15.5 x 110
19 *Psilastephanocolporites* "brevicolpatus"	28 x 25	hf	ev	PIN 42+100	6.9 x 109.9
20 *Psilastephanocolporites* "brevicolpatus"	28 x 25	mf	ev	PIN 42+100	6.9 x 109.9
21 *Psilastephanocolporites* "brevicolpatus"	28 x 28	mf	ev	PIN 52+110	8 x 90.9
22 *Psilastephanocolporites fissilis*	41 x 27	mf	ev	PIN 52+110	12.4 x 109.5
23 *Psilastephanocolporites fissilis*	17 x 22	mf	ev	PIN 28+0	11.6 x 108.2
24 *Psilastephanocolporites fissilis*	22 x 20	hf	pv	PIN 19+60	9.4 x 98.5
25 *Psilastephanocolporites* "pachyexinatus"	45 x 40	hf	pv	PIN 55+30	13.5 x 85.1
26 *Psilastephanocolporites* "pachyexinatus"	45 x 40	mf	pv	PIN 55+30	13.5 x 85.1
27 *Psilastephanocolporites* "pachyexinatus"	53 x 42	lf	ev	PIN 28+0	8.1 X 97.6
28 *Psilastephanocolporites* "pachyexinatus"	53 x 42	mf	ev	PIN 28+0	8.1 X 97.6

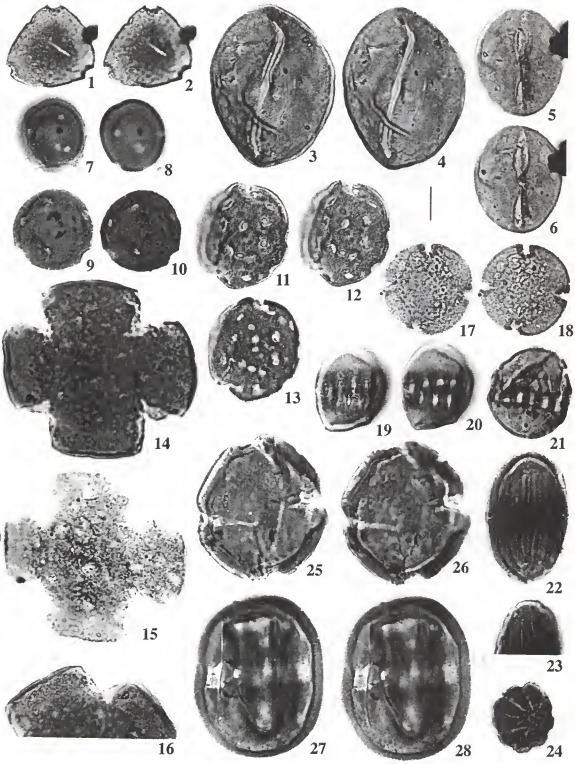
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Figure A-15. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Psilastephanocolporites* "psilatus"	52 x 48	hf	pv	PIN 81+0	14 x 91.5
2 *Psilastephanocolporites* "psilatus"	52 x 48	mf	pv	PIN 81+0	14 x 91.5
3 *Psilastephanoporites* "annulatus"	42 x 40	mf	pv	UR 761	16.2 x 86.9
4 *Psilastephanoporites* "annulatus"	42 x 40	mf	pv	UR 761	16.2 x 86.9
5 *Psilastephanoporites* "distinctus"	27 x 26	hf	pv	PIN 52+110	11.2 x 85.6
6 *Psilastephanoporites* "distinctus"	27 x 26	mf	pv	PIN 52+110	11.2 x 85.6
7 *Psilastephanoporites* "scabratus"	31 x 31	lf	pv	N 149	10.5 x 101.2
8 *Psilastephanoporites* "scabratus"	31 x 31	mf	pv	N 149	10.5 x 101.2
9 *Psilasyncolporites* "fastigiatus"	29 x 28	lf	pv	RE 132	19.5 x 111.1
10 *Psilasyncolporites* "fastigiatus"	29 x 28	mf	pv	RE 132	19.5 x 111.1
11 *Psilasyncolporites* "psilatus"	13 x 13	hf	pv	PIN 47+100	12.8 x 89.5
12 *Psilasyncolporites* "psilatus"	13 x 13	mf	pv	PIN 47+100	12.8 x 89.5
13 *Psilatricolporites* "crassicolumellatus"	30 x 20	hf	ev	PIN 52+110	5.5 x 112
14 *Psilatricolporites* "crassicolumellatus"	30 x 20	mf	ev	PIN 52+110	5.5 x 112
15 *Psilatricolporites* "crassicolumellatus"	30 x 20	lf	ev	PIN 52+110	5.5 x 112
16 *Psilatricolporites crassus*	43 x 43	mf	pv	PIN 12	12.3 x 84.5
17 *Psilatricolporites maculosus*	28 x 21	hf	ev	PIN 75+160	20 x 87
18 *Psilatricolporites maculosus*	28 x 21	mf	ev	PIN 75+160	20 x 87
19 *Psilatricolporites operculatus*	18 x 17	hf	pv	PIN 39+166	9.8 x 84.6
20 *Psilatricolporites* "orbicularis"	25 x 25	hf	pv	RE 143+120	20 x 93.7
21 *Psilatricolporites* "orbicularis"	25 x 25	hf	pv	RE 143+120	20 x 93.7
22 *Psilatricolporites* "orbicularis"	25 x 25	mf	pv	RE 143+120	20 x 93.7
23 *Psilatricolporites* "poricostatus"	30 x 25	mhf	pv	PIN 42+100	9.7 x 87.8
24 *Psilatricolporites* "poricostatus"	30 x 25	mmf	pv	PIN 42+100	9.7 x 87.8
25 *Psilatricolporites* "singularis"	31 x 31	hf	pv	PIN 42+100	20.6 x 100.2
26 *Psilatricolporites* "singularis"	31 x 31	mhf	pv	PIN 42+100	20.6 x 100.2
27 *Psilatricolporites* "singularis"	31 x 31	mf	pv	PIN 42+100	20.6 x 100.2
28 *Psilatricolporites* "singularis"	31 x 31	lf	pv	PIN 42+100	20.6 x 100.2
29 *Psilatricolporites* "spongiosus"	33 x 28	mf	ev	N 149	6.2 x 93
30 *Psilatricolporites* "spongiosus"	33 x 28	mf	ev	N 149	6.2 x 93
31 *Psilatricolporites transversalis*	31 x 25	mf	ev	PIN 52+110	9.7 x 110.4
32 *Psilatricolporites triangularis*	25 x 25	mf	pv	PIN 81+0	10.9 x 87.6
33 *Psilatriporites* "tenuiexinatus"	30 x 24	hf	pv	UR 531+120	12.3 x 106.2
34 *Psilatriporites* "tenuiexinatus"	30 x 24	mf	pv	UR 531+120	12.3 x 106.2
35 *Racemonocolpites facilis*	50 x 33	mf	ev	UR 812	13.9 x 104.4
36 *Retibrevitricolpites retibolus*	16 x 16	hf	ev	PIN 39+166	8.5 x 111.7
37 *Retibrevitricolpites retibolus*	16 x 16	mf	ev	PIN 39+166	8.5 x 111.7
38 *Retibrevitricolpites* "santanderensis"	30 x 29	mf	pv	RE 143+120	19.2 x 104
39 *Retibrevitricolpites* "santanderensis"	22 x 22	mf	pv	PIN 39+166	3.2 x 114.5

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Figure A-16. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Racemonocolpites* "costagemmatus"	50 x 48	hf	ev	N 354+120	9.9 x 93.5
2 *Racemonocolpites* "costagemmatus"	50 x 48	mf	ev	N 354+120	9.9 x 93.5
3 *Racemonocolpites racematus*	36 x 22	mf	ev	N 27	8.2 x 85.7
4 *Racemonocolpites racematus*	53 x 34	mf	?	RE 67+120	16.2 x 99.4
5 *Retibrevitricolpites* "costatus"	33 x 32	hf	pv	PIN 81+0	17.9 x 80.8
6 *Retibrevitricolpites* "costatus"	33 x 32	mf	pv	PIN 81+0	17.9 x 80.8
7 *Retibrevitricolpites triangulatus*	19 x 18	hf	pv	UR 812	10.6 x 92.9
8 *Retibrevitricolpites triangulatus*	19 x 18	hmf	pv	UR 812	10.6 x 92.9
9 *Retibrevitricolporites* "grandis"	30 x 30	hf	pv	PIN 0	14.9 x 111.5
10 *Retibrevitricolporites* "grandis"	30 x 30	mf	pv	PIN 0	14.9 x 111.5
11 *Retibrevitricolporites* "speciosus"	26 x 27	lf	pv	N 354+120	3.9 x 82.1
12 *Retibrevitricolporites* "speciosus"	26 x 27	mhf	pv	N 354+120	3.9 x 82.1
13 *Retibrevitricolporites* "speciosus"	26 x 27	hf	pv	N 354+120	3.9 x 82.1
14 *Retidiporites elongatus*	30 x 28	lf	pv	N 110	7.4 x 79.5
15 *Retidiporites elongatus*	30 x 28	mf	pv	N 110	7.4 x 79.5
16 *Retidiporites magdalenensis*	32 x 23	mf	pv	N4	18.6 x 95
17 *Retidiporites* "poricostatus"	42 x 22	hf	pv	N 45	3.9 x 90.4
18 *Retidiporites* "poricostatus"	42 x 22	hmf	pv	N 45	3.9 x 90.4
19 *Retidiporites* "poricostatus"	42 x 22	mlf	pv	N 45	3.9 x 90.4
20 *Retimonocolpites* "ovatum"	40 x 35	hf	ev	NA 59+90	6.6 x 83.5
21 *Retimonocolpites* "ovatum"	40 x 35	mf	ev	NA 59+90	6.6 x 83.5
22 *Retimonocolpites regio*	40 x 21	hf	ev	N 4	7.6 x 85.3
23 *Retimonocolpites regio*	40 x 21	mf	ev	N 4	7.6 x 85.3
24 *Retipollenites* "baculatus"	40 x 26	hf		N 18	14 x 82.7
25 *Retipollenites* "baculatus"	40 x 26	mf		N 18	14 x 82.7
26 *Retipollenites* "magnus"	100 x 70	hf		N 114	12.3 x 110.5
27 *Retipollenites* "magnus"	100 x 70	lf		N 114	12.3 x 110.5
28 *Retipollenites* "magnus"	27 x 35	hf		N 114	12.3 x 110.5
29 *Retistephanocolpites angeli*	58 x 49	mf	pv	N 27	20.3 x 101.2
30 *Retistephanocolpites angeli*	58 x 49	mf	pv	N 27	20.3 x 101.2

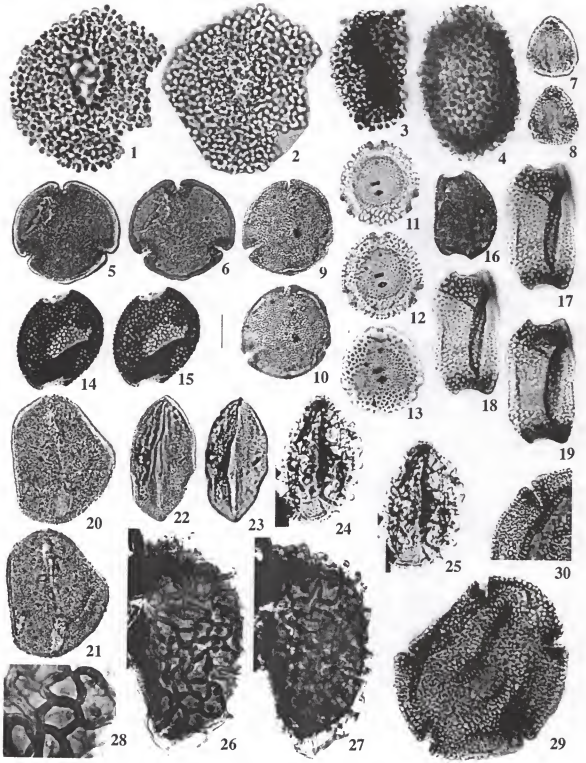
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Figure A-17. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Retistephanocolpites* "fossulatus"	53 x 40	hf	pv	PIN 35+90	15 x 94
2 *Retistephanocolpites* "fossulatus"	53 x 40	mhf	pv	PIN 35+90	15 x 94
3 *Retistephanocolpites* "fossulatus"	53 x 40	lf	pv	PIN 35+90	15 x 94
4 *Retistephanocolpites* "gradatum"	40 x 35	mf	pv	PIN 42+100	20 x 110
5 *Retistephanocolpites* "gradatum"	40 x 35	lf	pv	PIN 42+100	20 x 110
6 *Retistephanocolpites* "inciertus"	30 x 30	lf	pv	PIN 52+110	22.3 x 80.3
7 *Retistephanocolpites* "inciertus"	30 x 30	mf	pv	PIN 52+110	22.3 x 80.3
8 *Retistephanocolporites festivus*	35 x 35	mf	pv	PIN 42+100	19.7 x 98.2
9 *Retistephanocolporites festivus*	45 x 45	mf	pv	PIN 35+90	7.6 x 111.4
10 *Retistephanocolporites* "fossulatus"	26 x 26	hf	pv	PIN 28+0	7.8 x 97.9
11 *Retistephanocolporites* "fossulatus"	26 x 26	hmf	pv	PIN 28+0	7.8 x 97.9
12 *Retistephanocolporites* "fossulatus"	26 x 26	mf	pv	PIN 28+0	7.8 x 97.9
13 *Retistephanocolporites* "fossulatus"	26 x 26	lf	pv	PIN 28+0	7.8 x 97.9
14 *Retistephanoporites angelicus*	28 x 25	hf	pv	PIN 55+30	11 x 113.5
15 *Retistephanoporites angelicus*	28 x 25	mf	pv	PIN 55+30	11 x 113.5
16 *Retistephanoporites* "crassiexinatus"	37 x 35	hf	pv	PIN 28+0	5.2 x 85.6
17 *Retistephanoporites* "crassiexinatus"	37 x 35	mf	pv	PIN 28+0	5.2 x 85.6
18 *Retistephanoporites* "minutipori"	35 x 35	hf	pv	PIN 28+0	11.4 x 98.4
19 *Retistephanoporites* "minutipori"	35 x 35	mf	pv	PIN 28+0	11.4 x 98.4
20 *Retistephanoporites* "regaloi"	30 x 30	hf	pv	La Paz 712m	12.7 x 107.9
21 *Retistephanoporites* "regaloi"	30 x 30	mf	pv	La Paz 712m	12.7 x 107.9
22 *Retisyncolporites angularis*	46 x 42	hmf	pv	RE 251+30	5.5 x 100
23 *Retisyncolporites* "complicatus"	30 x 30	hf	pv	PIN 81+0	3.1 x 95.1
24 *Retisyncolporites* "complicatus"	30 x 30	mf	pv	PIN 81+0	3.1 x 95.1
25 *Retisyncolporites* "delicatus"	50 x 50	hf	pv	PIN 12	5 x 100.9
26 *Retisyncolporites* "delicatus"	50 x 50	mf	pv	PIN 12	5 x 100 9
27 *Retisyncolporites* "delicatus"	40 x 40	mf	pv	N 354+120	11.6 x 85.3

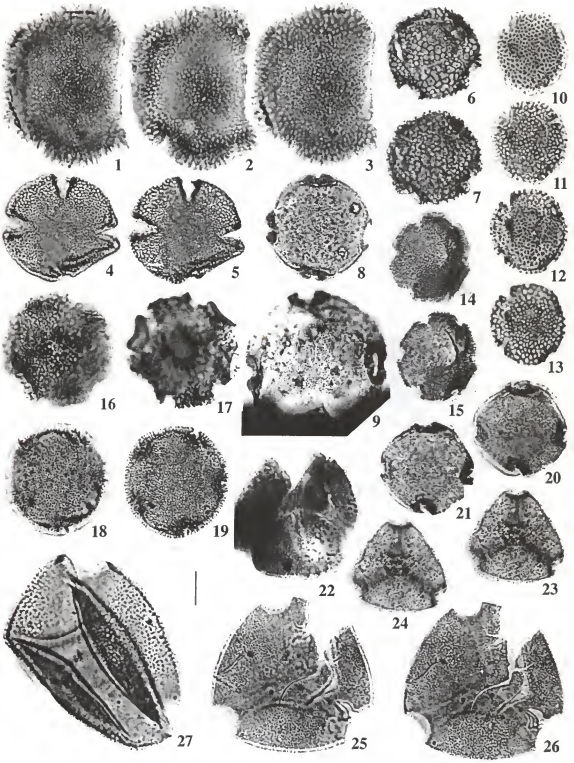
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Figure A-18. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Retitricolpites absolutus*	27 x 24	hf	ev	PIN 55+30	4.8 x 10.4
2 *Retitricolpites absolutus*	27 x 24	mf	ev	PIN 55+30	4.8 x 10.4
3 *Retitricolpites antonii*	26 x 15	hf	pv	PIN 32+0	14.2 x 107.9
4 *Retitricolpites antonii*	26 x 15	mf	pv	PIN 32+0	14.2 x 107.9
5 *Retitricolpites* "baculensis"	50 x 35	hf	pv	N 74+0	13.8 x 82.1
6 *Retitricolpites* "baculensis"	50 x 35	mf	pv	N 74+0	13.8 x 82.1
7 *Retitricolpites* "baculensis"	50 x 35	lf	pv	N 74+0	13.8 x 82.1
8 *Retitricolpites* "baculensis"	24 x 17	hf	pv	PIN 81+0	18.1 x 111.6
9 *Retitricolpites clarensis*	35 x 35	hf	pv	PIN 32+0	12.4 x 97.6
10 *Retitricolpites* "costatus"	42 x 40	mhf	pv	PIN 71+0	42 x 40
11 *Retitricolpites* "costatus"	42 x 40	mf	pv	PIN 71+0	42 x 40
12 *Retitricolpites florentinus*	40 x 25	hf	ev	PIN 81+0	9.1 x 89.1
13 *Retitricolpites florentinus*	40 x 25	mf	ev	PIN 81+0	9.1 x 89.1
14 *Retitricolpites magnus*	55 x 31	mf	ev	PIN 32+0	19.4 x 88.8
15 *Retitricolpites magnus*	55 x 31	lf	ev	PIN 32+0	19.4 x 88.8
16 *Retitricolpites* "marginocostatus"	40 x 38	hf	pv	PIN 19+60	40 x 38
17 *Retitricolpites* "marginocostatus"	40 x 38	mf	pv	PIN 19+60	40 x 38
18 *Retitricolpites* "peculiaris"	50 x 45	mf	pv	NA 46	11.3 x 95.9
19 *Retitricolpites* "peculiaris"	50 x 45	mf	pv	NA 46	11.3 x 95.9
20 *Retitricolpites* "peculiaris"	21 x 19	retic.	pv	NA 46	11.3 x 95.9
21 *Retitricolpites* "peculiaris"	40 x 23	mf	ev	NA 46	22 x 91
22 *Retitricolpites* "peculiaris"	45 x 35	mf	pv	NA 46	11.5 x 96.5
23 *Retitricolpites perforatus*	32 x 28	hf	pv	RE 67+120	14.5 x 109.5
24 *Retitricolpites perforatus*	32 x 28	hmf	pv	RE 67+120	14.5 x 109.5
25 *Retitricolpites perforatus*	32 x 28	mf	pv	RE 67+120	14.5 x 109.5

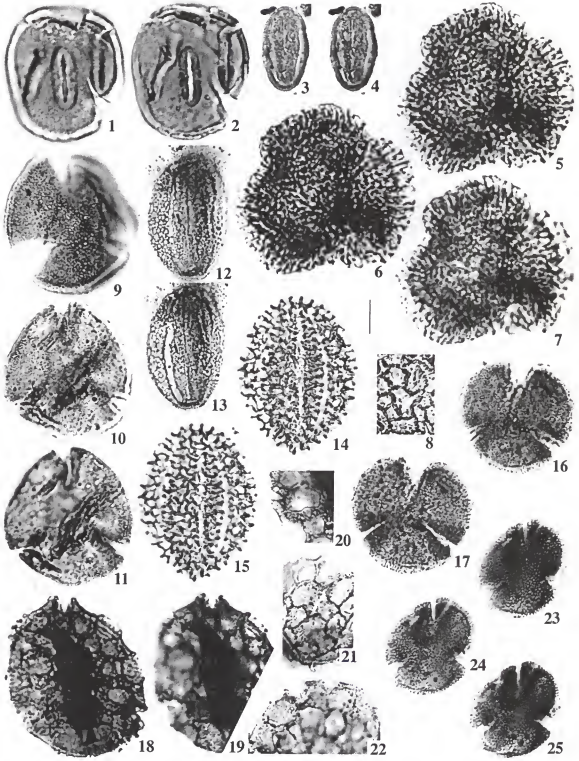
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Figure A-19. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Retitricolpites* "protoclarensis"	33 x 31	hf	pv	N 120	15 x 91.8
2 *Retitricolpites* "protoclarensis"	33 x 31	mf	pv	N 120	15 x 91.8
3 *Retitricolpites saturum*	40 x 40	hf	pv	N 110	7.3 x 88.7
4 *Retitricolpites saturum*	40 x 40	mf	pv	N 110	7.3 x 88.7
5 *Retitricolporites* "arctus"	30 x 19	hf	ev	PIN 42+100	8.3 x 78.5
6 *Retitricolporites* "arctus"	30 x 19	mf	ev	PIN 42+100	8.3 x 78.5
7 *Retitricolporites cienagensis*	31 x 29	mf	pv	PIN 35+90	21 x 110
8 *Retitricolporites* "delicatus"	33 x 30	hf	pv	PIN 52+110	11 x 91.5
9 *Retitricolporites* "delicatus"	33 x 30	mf	pv	PIN 52+110	11 x 91.5
10 *Retitricolporites* "distinctus"	40 x 28	mf	ev	N 120	18.2 x 85.2
11 *Retitricolporites* "distinctus"	40 x 28	lf	ev	N 120	18.2 x 85.2
12 *Retitricolporites* "grandis"	50 x 50	hf	pv	RE 67+120	2.9 x 90.3
13 *Retitricolporites* "grandis"	50 x 50	mf	pv	RE 67+120	2.9 x 90.3
14 *Retitricolporites guianensis*	30 x 22	hf	ev	PIN 32+0	9.8 x 91
15 *Retitricolporites guianensis*	30 x 22	mf	ev	PIN 32+0	9.8 x 91
16 *Retitricolporites hispidus*	28 x 18	mf	ev	PIN 39+166	17.6 x 105
17 *Retitricolporites* "insolitus"	60 x 60	hf	pv	PIN 81+0	18.2 x 79.5
18 *Retitricolporites* "insolitus"	60 x 60	mf	pv	PIN 81+0	18.2 x 79.5
19 *Retitricolporites irregularis*	28 x 25	hf	pv	N 354+120	7.3 x 103.8
20 *Retitricolporites* "longicolpis"	40 x 40	hf	pv	PIN 55+30	7.3 x 89.5
21 *Retitricolporites* "longicolpis"	40 x 40	mf	pv	PIN 55+30	7.3 x 89.5
22 *Retitricolporites* "marginatus"	50 x 45	hf	pv	PIN 28+0	6 x 106.5
23 *Retitricolporites* "marginatus"	50 x 45	mf	pv	PIN 28+0	6 x 106.5
24 *Retitricolporites* "marginatus"	50 x 45	lf	pv	PIN 28+0	6 x 106.5

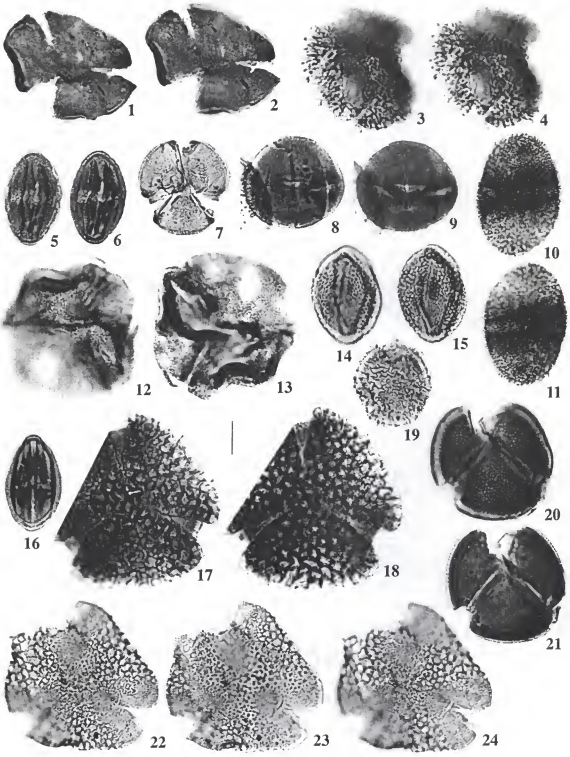
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Figure A-20. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Retitricolporites mariposus*	28 x 25	hf	pv	N 265	13.7 x 109.1
2 *Retitricolporites mariposus*	28 x 25	lf	pv	N 265	13.7 x 109.1
3 *Retitricolporites mariposus*	28 x 25	mf	pv	N 265	13.7 x 109.1
4 *Retitricolporites medius*	22 x 20	mf	ev	N 354+120	7.5 x 109.3
5 *Retitricolporites* "minutus"	25 x 20	hf	ev	PIN 39+166	6.9 x 110.5
6 *Retitricolporites* "minutus"	25 x 20	mf	ev	PIN 39+166	6.9 x 110.5
7 *Retitricolporites* "pachynexinatus"	30 x 30	hf	pv	PIN 42+100	15.8 x 98.4
8 *Retitricolporites* "pachynexinatus"	30 x 30	mf	pv	PIN 42+100	15.8 x 98.4
9 *Retitricolporites* "poricostatus"	25 x 25	hf	pv	N 354+120	11.6 x 107
10 *Retitricolporites* "poricostatus"	25 x 25	mf	pv	N 354+120	11.6 x 107
11 *Retitricolporites* "poricostatus"	25 x 25	lf	pv	N 354+120	11.6 x 107
12 *Retitricolporites squarrosus*	26 x 23	hf	ev	PIN 35+90	12.5 x 104.1
13 *Retitricolporites squarrosus*	26 x 23	mf	ev	PIN 35+90	12.5 x 104.1
14 *Retitricolporites* "tropicalis"	28 x 25	hf	pv	N 74	7.2 x 106.5
15 *Retitricolporites* "tropicalis"	28 x 25	mf	pv	N 74	7.2 x 106.5
16 *Retitricolporites* "tropicalis"	24 x 23	hf	ev	N 74	6.5 x 85
17 *Retitricolporites* "tropicalis"	24 x 23	mf	ev	N 74	6.5 x 85
18 *Retitricolporites* "vestibulatus"	40 x 40	hf	pv	N 174	6.4 x 83.8
19 *Retitricolporites* "vestibulatus"	40 x 40	mf	pv	N 174	6.4 x 83.8
20 *Retitricolporites* "vestibulatus"	40 x 40	lf	pv	N 174	6.4 x 83.8
21 *Retitriporites* "amplireticulatus"	40 x 40	hf	ev	N 110	6.9 x 97.3
22 *Retitriporites* "amplireticulatus"	40 x 40	mf	ev	N 110	6.9 x 97.3
23 *Retitriporites* "amplireticulatus"	40 x 40	lf	ev	N 110	6.9 x 97.3
24 *Retitriporites* "annulatus"	38 x 30	hf	pv	N 27	20 x 96.5
25 *Retitriporites* "annulatus"	38 x 30	mf	pv	N 27	20 x 96.5
26 *Retitriporites* "pachyexinatus"	25 x 25	hf	pv	PIN 42+100	4.9 x 93.1
27 *Retitriporites* "pachyexinatus"	25 x 25	mf	pv	PIN 42+100	4.9 x 93.1
28 *Retitriporites* "peculiaris"	40 x 38	hf	pv	PIN 35+90	5.6 x 84.5
29 *Retitriporites* "peculiaris"	40 x 38	hf	pv	PIN 35+90	5.6 x 84.5
30 *Retitriporites* "perforatus"	29 x 27	mf	ev	PIN 52+110	5 x 87.5
31 *Retitriporites* "perforatus"	29 x 27	lf	ev	PIN 52+110	5 x 87.5
32 *Retitriporites* "poricostatus"	35 x 32	lf	pv	PIN 71+0	18.1 x 82
33 *Retitriporites* "poricostatus"	35 x 32	mf	pv	PIN 71+0	18.1 x 82

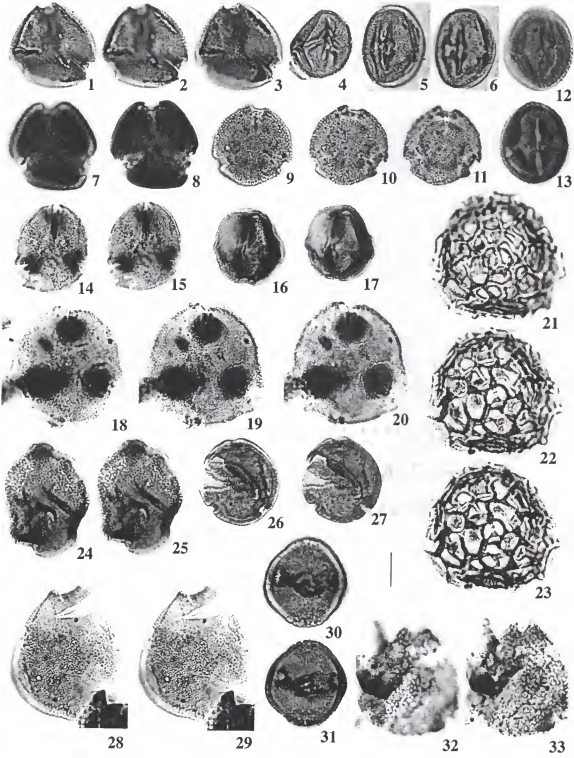
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Figure A-21. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Rugotricolporites felix*	31 x 25	hf	ev	PIN 28+0	17.7 x 81.5
2 *Rugotricolporites felix*	31 x 25	mf	ev	PIN 28+0 ,	17.7 x 81.5
3 *Scabrastephanocolpites* "casanaris"	40 x 35	hf	pv	N 265	20 x 102
4 *Scabrastephanocolpites* "casanaris"	40 x 35	mf	pv	N 265	20 x 102
5 *Scabratricolporites* "amplocolpatus"	32 x 25	hf	ev	UR 812	10.5 x 91.5
6 *Scabratricolporites* "amplocolpatus"	32 x 25	mf	ev	UR 812	10.5 x 91.5
7 *Scabratricolporites* "amplocolpatus"	32 x 30	mf	pv	UR 531+120	10.5 x 82.8
8 *Scabratricolporites* "tomassoi"	27 x 26	hf	pv	PIN 42+100	11.9 x 103
9 *Scabratricolporites* "tomassoi"	27 x 26	mf	pv	PIN 42+100	11.9 x 103
10 *Scabratriporites* "bellus"	36 x 31	hf	pv	RE 251+30	5.1 x 98.2
11 *Scabratriporites* "bellus"	36 x 31	mf	pv	RE 251+30	5.1 x 98.2
12 *Spinizonocolpites* "brevibaculatus"	36 x 36	mf	ev	UR 531+120	14 x 108.5
13 *Spinizonocolpites* "brevibaculatus"	45 x 40	hf	ev	UR 531+120	21.5 x 97
14 *Spinizonocolpites* "brevibaculatus"	45 x 40	mf	ev	UR 531+120	21.5 x 97
15 *Spinizonocolpites* "breviechinatus"	65 x 40	hf	pv	N 110	14.8 x 110.2
16 *Spinizonocolpites* "breviechinatus"	65 x 40	mf	pv	N 110	14.8 x 110.2
17 *Spinizonocolpites* "breviechinatus"	40 x 38	mf	ev	N 74	8.2 x 95
18 *Spinizonocolpites* "grandis"	75 x 57	mf	pv	PIN 12	11.4 x 111.2
19 *Spinizonocolpites* "grandis"	40 x 36	lf	pv	PIN 12	11.4 x 111.2
20 *Spinizonocolpites* "grandis"	34 x 42	mf	pv	PIN 12	11.4 x 111.2
21 *Spinizonocolpites* "pachyexinatus"	80 x 43	hf	pv	N 174	13 x 108
22 *Spinizonocolpites* "pachyexinatus"	80 x 43	mf	pv	N 174	13 x 108

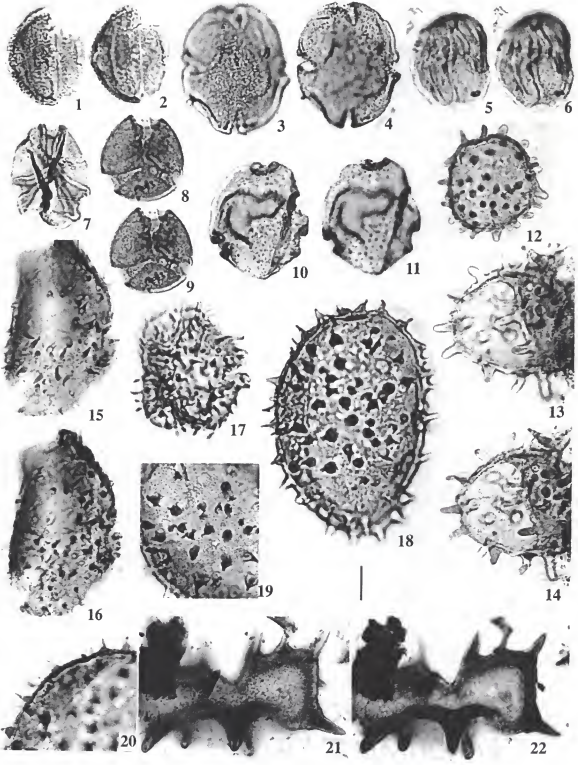
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Figure A-22. Illustration of palynomorphs
see key to labels in Figure A-1

taxa	size	focus	view	slide	coordenates
1 *Spinizonocolpites* "pluribaculatus"	55 x 40	hf	pv	UR 761	17.5 x 92.3
2 *Spinizonocolpites* "pluribaculatus"	55 x 40	mf	pv	UR 761	17.5 x 92.3
3 *Spirosyncolpites spiralis*	50 x 50	hf		PIN 81+0	17.9 x 104.5
4 *Spirosyncolpites spiralis*	50 x 50	mf		PIN 81+0	17.9 x 104.5
5 *Spirosyncolpites spiralis*	30 x 19	colpus		PIN 32+0	19 x 101.8
6 *Striatricolpites catatumbus*	42 x 30	hf	ev	PIN 66+80	15.6 x 108.5
7 *Striatricolpites catatumbus*	42 x 30	mf	ev	PIN 66+80	15.6 x 108.5
8 *Striatricolpites minor*	18 x 18	mf	e/pv	N 120	11.9 x 115.1
9 *Striatricolpites* "orinocus"	41 x 20	hf	ev	N 74	5 x 96.6
10 *Striatricolpites* "orinocus"	41 x 20	hf	ev	N 74	5 x 96.6
11 *Striatricolpites* "tenuistriatus"	38 x 31	hf	ev	RE 143+120	15.6 x 95.2
12 *Striatricolpites* "tenuistriatus"	38 x 31	mf	ev	RE 143+120	15.6 x 95.2
13 *Striatricolpites* "tenuistriatus"	45 x 30	mf	ev	UR 812	17.8 x 89.4
14 *Striatricolporites* "digitatus"	35 x 20	mf	ev	N 21+100	16 X 101.9
15 *Striatricolporites* "digitatus"	35 x 20	hf	ev	N 21+100	16 X 101.9
16 *Striatricolporites* "reticulatus"	30 x 22	hf	ev	N 149	19 x 91
17 *Striatricolporites* "reticulatus"	30 x 22	mf	ev	N 149	19 x 91
18 *Syncolporites lisamae*	16 x 16	hf	pv	N 87	11.4 x 84.1
19 *Syncolporites lisamae*	16 x 16	mf	pv	N 87	11.4 x 84.1
20 *Syncolporites marginatus*	20 x 17	lf	pv	RE 113	11.5 x 109.4
21 *Syncolporites marginatus*	20 x 17	mf	pv	RE 113	11.5 x 109.4
22 *Syncolporites* "verrucatus"	17 x 15	lf	pv	N 174	12.2 x 114
23 *Syncolporites* "verrucatus"	17 x 15	hf	pv	N 174	12.2 x 114
24 *Ulmoideipites krempii*	26 x 26	hf	pv	N 149	18.6 x 96.9
25 *Verrustephanocolpites* "rugulatus"	34 x 33	lf	pv	N 265	18.2 x 109.2
26 *Verrustephanoporites* "gemmatus"	29 x 26	hf	pv	PIN 52+110	4.3 x 104
27 *Verrustephanoporites* "gemmatus"	29 x 26	mf	pv	PIN 52+110	4.3 x 104
28 *Verrutricolpites* "irregularis"	33 x 31	lf	pv	PIN 81+0	8.8 x 87.2
29 *Verrutricolpites* "irregularis"	33 x 31	mf	pv	PIN 81+0	8.8 x 87.2
30 *Wilsonipites margocolpatus*	30 x 25	mf	pv	RE 132	6.4 x 102.3
31 *Verrutricolporites* "reticulatus"	43 x 40	hf	pv	PIN 52+110	10.5 x 98
32 *Verrutricolporites* "reticulatus"	43 x 40	mf	pv	PIN 52+110	10.5 x 98
33 *Verrutricolporites* "reticulatus"	42 x 44	mf	pv	PIN 81+0	7.6 x 105.5
34 *Zonocostites* "minor"	14 x 15	mf	pv	PIN 52+110	8.4 x 99.2
35 *Zonocostites* "minor"	11 x 10	mf	ev	PIN 52+110	6.5 x 97.9
36 *Zonocostites* "minor"	12 x 11	mf	ev	PIN 52+110N(	15.4 x 97.5

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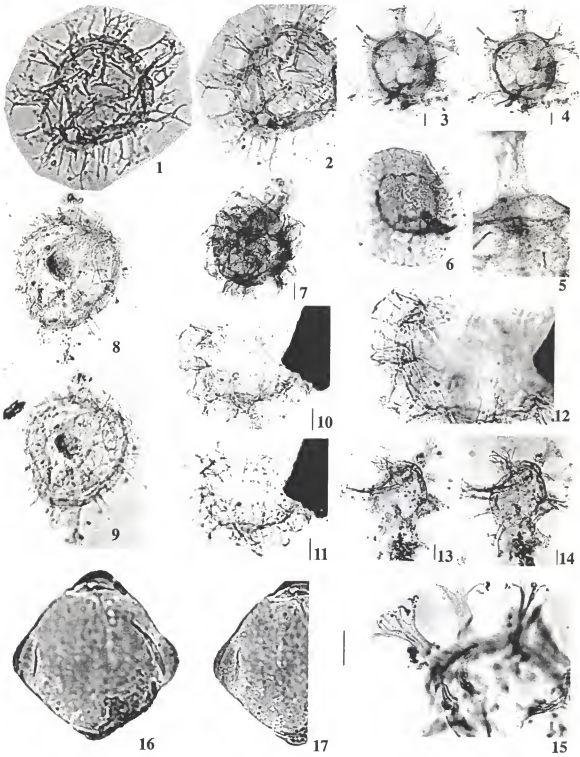
Figure A-23. Illustration of palynomorphs
vv=ventral view, AP=archeopyle, lv=lateral view,
hv=hypocystal view, pv=proximal view

taxa	size	focus	view	slide	coordenates
1 *Achomosphaera* sp. A	55 x 50	lf	vv	PIN 12	6.4 x 94
2 *Achomosphaera* sp. A	55 x 50	mf	vv	PIN 12	6.4 x 94
3 *Cordosphaeridium* sp. A	100 x 10(	hf	vv	PIN 47+100	20.6 x 95.7
4 *Cordosphaeridium* sp. A	100 x 10(	lf	vv	PIN 47+100	20.6 x 95.7
5 *Cordosphaeridium* sp. A	43 x 30	mf	vv	PIN 47+100	20.6 x 95.7
6 *Cordosphaeridium* sp. A	35 x 32	mf	AP	PIN 12	4 x 95.2
7 *Cordosphaeridium* sp. A	80 x 75	hf	lv	PIN 12	10.5 x 102.5
8 *Coronifera* sp. A	50 x 40	hf	lv	N 174	13.1 x 80
9 *Coronifera* sp. A	50 x 40	hf	lv	N 174	13.1 x 80
10 *Glaphyrocysta* sp. A	70 x 60	hf	vv	PIN 35+90	18.4 x 104.3
11 *Glaphyrocysta* sp. A	70 x 60	lf	vv	PIN 35+90	18.4 x 104.3
12 *Glaphyrocysta* sp. A	70 x 60	mf	vv	PIN 35+90	18.4 x 104.3
13 *Homotryblium floripes*	90 x 82	hf	hv	PIN 28+0	11.3 x 90.1
14 *Homotryblium floripes*	90 x 82	lf	hv	PIN 28+0	11.3 x 90.1
15 *Homotryblium floripes*	90 x 82	mf	hv	PIN 28+0	11.3 x 90.1
16 Incertae sedis A	50 x 50	mf	pv	PIN 42+100	23 x 95.4
17 Incertae sedis A	50 x 50	mf	pv	PIN 42+100	23 x 95.4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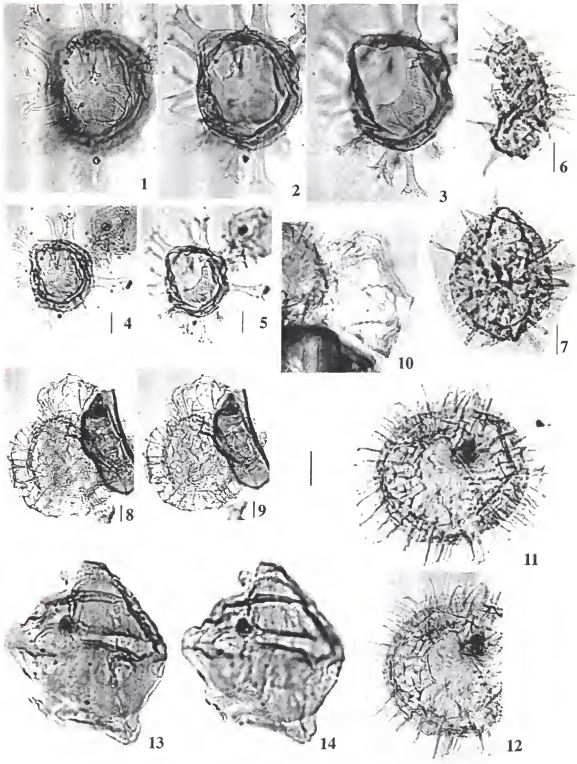
16
17

Figure A-24. Illustration of palynomorphs
see key to labels in Figure A-23

taxa	size	focus	view	slide	coordenates
1 *Hystrichosphaeridium* sp. A	70 x 70	hf	hv	PIN 28+0	12 x 107
2 *Hystrichosphaeridium* sp. A	70 x 70	mf	hv	PIN 28+0	12 x 107
3 *Hystrichosphaeridium* sp. A	70 x 70	lf	hv	PIN 28+0	12 x 107
4 *Hystrichosphaeridium* sp. A	70 x 70	hf	hv	PIN 28+0	12 x 107
5 *Hystrichosphaeridium* sp. A	70 x 70	lf	hv	PIN 28+0	12 x 107
6 *Lingulodinium* cf. *sicula*	50 x 40	mf	lv	PIN 35+90	10.3 x 92.9
7 *Lingulodinium* cf. *sicula*	60 x 53	mf	lv	PIN 52+110	15.7 x 103
8 *Nematosphaeropsis* sp. A	90 x 80	hf	dvv	PIN 12	18.6 x 82
9 *Nematosphaeropsis* sp. A	90 x 80	lf	dvv	PIN 12	18.6 x 82
10 *Nematosphaeropsis* sp. A	90 x 80	hf	dvv	PIN 12	18.6 x 82
11 *Polysphaeridium* sp. A	68 x 66	lf	lv	PIN 12	5 x 105.7
12 *Polysphaeridium* sp. A	68 x 66	mf	lv	PIN 12	5 x 105.7
13 *Senegalinium* sp. A	60 x 52	mf	vv	RE 67+120	6 x 92.1
14 *Senegalinium* sp. A	60 x 52	lf	vv	RE 67+120	6 x 92.1


1
2
3
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4
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10
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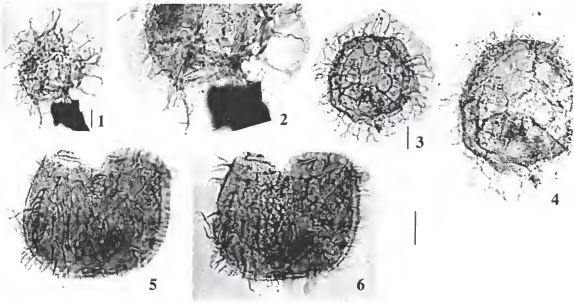
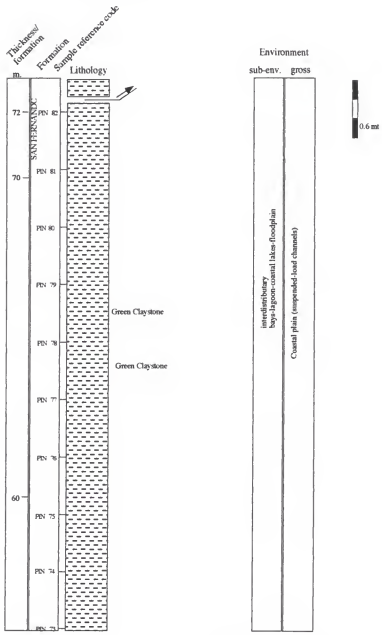
8
9
11
13
14
12

Figure A-25. Illustration of palynomorphs
see key to labels in Figure A-23

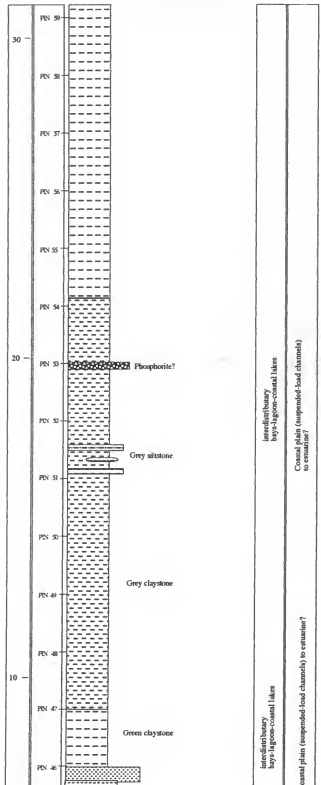
taxa	size	focus	view	slide	coordenates
1 *Spiniferites* cf. *mirabilis*	75 x 60	lf	vv	UR 726	9.8 x 107.3
2 *Spiniferites* cf. *mirabilis*	75 x 60	mf	vv	UR 726	9.8 x 107.3
3 *Spiniferites* sp. A	60 x 56	lf	dvl	PIN 12	17.8 x 99.2
4 *Spiniferites* sp. A	60 x 56	mf	dvl	PIN 12	17.8 x 99.2
5 *Systematophora?* sp. A	55 x 50	hf	dvv	PIN 28+0	12.5 x 83.6
6 *Systematophora* ? sp. A	55 x 50	mf	dvv	PIN 28+0	12.5 x 83.6

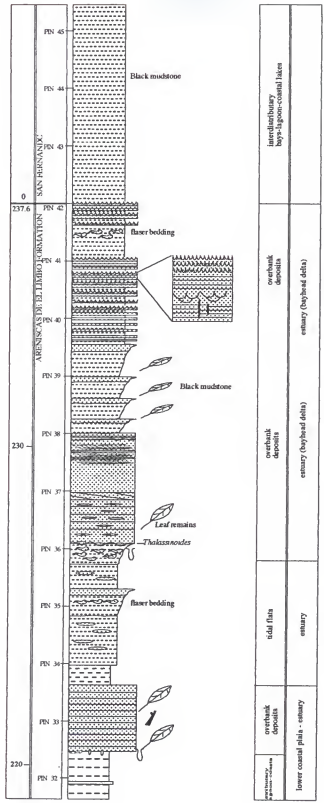

1
2
3
4
5
6

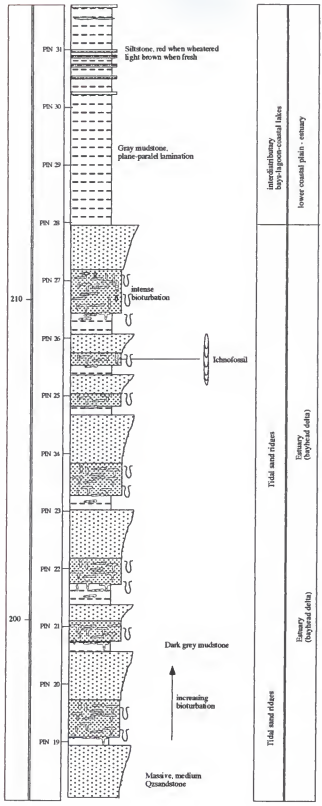
APPENDIX B
LITHOLOGICAL DESCRIPTION OF THE PINALERITA SECTION

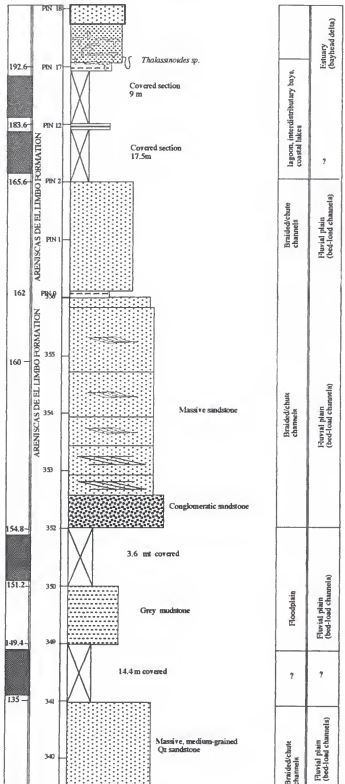


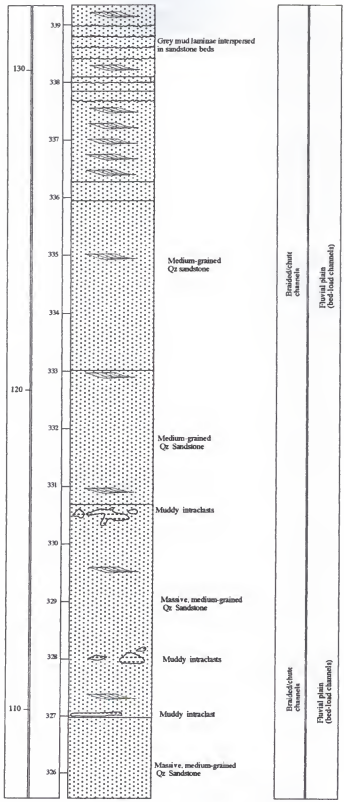
PIN 72
PIN 71
PIN 70
PIN 69
PIN 68
PIN 67
PIN 66
PIN 65
PIN 64
PIN 63
PIN 62
PIN 61
PIN 60
50
40
Green Claystone
interdistributary
bays-lagoon-coastal lakes-floodplain
interdistributary
bays-lagoon-coastal lakes
Coastal plain (suspended-load channels)
Coastal plain (suspended-load channels)

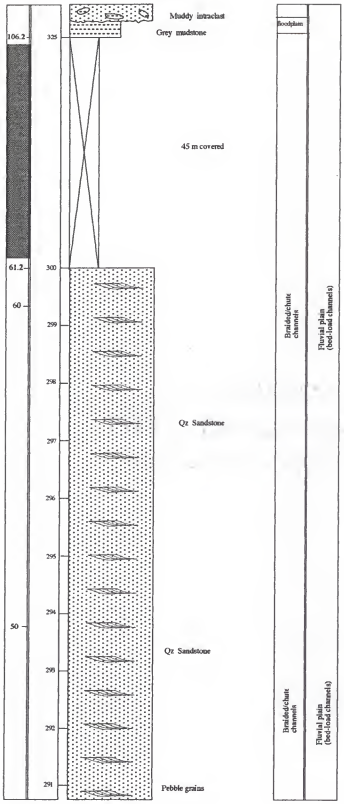

30
20
10
PDV 59
PDV 58
PDV 57
PDV 56
PDV 55
PDV 54
PDV 53
PDV 52
PDV 51
PDV 50
PDV 49
PDV 48
PDV 47
PDV 46
Phosphorite?
Grey siltstone
Grey claystone
Green claystone
interdistributary bays-lagoon-coastal lakes
Coastal plain (suspended-load channels) to estuarine?
interdistributary bays-lagoon-coastal lakes
Coastal plain (suspended-load channels) to estuarine?

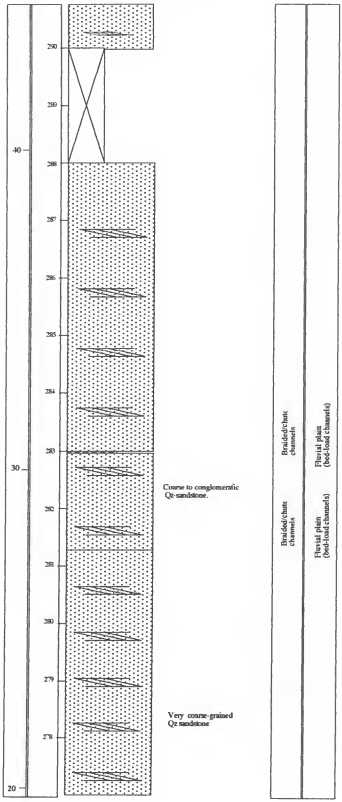

0
237.6
230
220
SAN PEDRO NOC
ARENISCAS DE EL HIERRO FORMATION
PEN 45
PEN 44
PEN 43
PEN 42
PEN 41
PEN 40
PEN 39
PEN 38
PEN 37
PEN 36
PEN 35
PEN 34
PEN 33
PEN 32
Black mudstone
flaser bedding
Black mudstone
Leaf remains
Thalassinoides
flaser bedding
overbank deposits
tidal flats
overbank deposits
overbank deposits
estuary (bayhead delta)
estuary
estuary (bayhead delta)
estuary (bayhead delta)
lower coastal plain - estuary
interdistributary bays-lagoon-coastal lakes

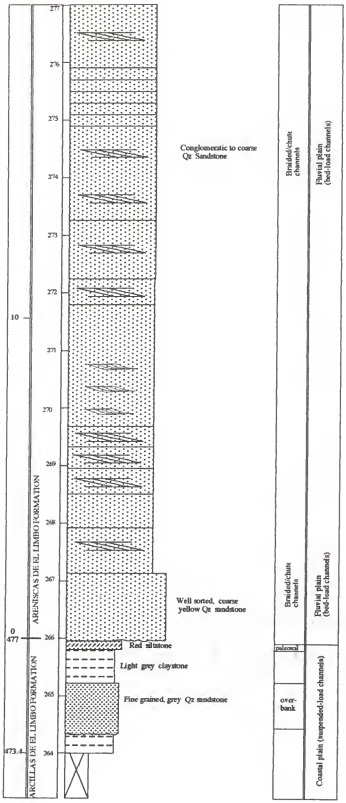

PIN 31
PIN 30
PIN 29
PIN 28
PIN 27
PIN 26
PIN 25
PIN 24
PIN 23
PIN 22
PIN 21
PIN 20
PIN 19
210
200
Siltstone, red when wheatered
light brown when fresh
Grey mudstone,
plane-paralel lamination
intense
bioturbation
Ichnofosil
Dark grey mudstone
increasing
bioturbation
Massive, medium
Qnsandstone
Tidal sand ridges
Estuary
(bayhead delta)
Tidal sand ridges
Estuary
(bayhead delta)
interdistributary
bays-lagoon-coastal lakes
lower coastal plain - estuary

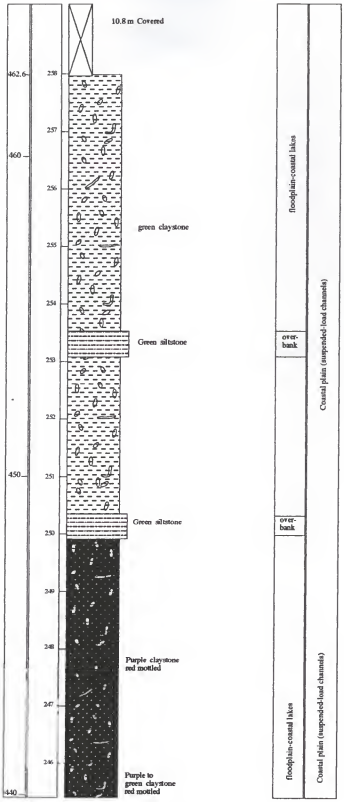

ARENISCAS DE EL LIMBO FORMATION
PIN 18
PIN 17
PIN 12
PIN 2
PIN 1
PIN 0
192.6
183.6
165.6
162
160
154.8
151.2
149.4
135
355
354
353
352
350
349
341
340
Thalassinoides sp.
Covered section 9 m
Covered section 17.5m
Massive sandstone
Conglomeratic sandstoce
3.6 mt covered
Grey mudstone
14.4 m covered
Massive, medium-grained Qz sandstone
Braided/chute channels
Floodplain
Fluvial plain (bed-load channels)
Lagoon, interdistributary bays, coastal lakes
Estuary (boyhead delta)
0.6 mt

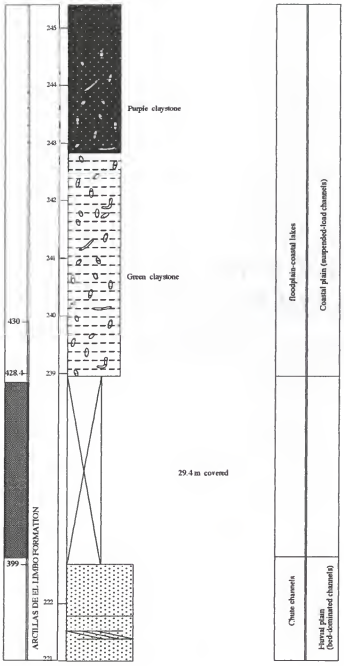

339
130
338
337
336
335
334
333
120
332
331
330
329
328
110
327
326
Grey mud laminae interspersed in sandstone beds
Medium-grained Qz sandstone
Medium-grained Qz Sandstone
Muddy intraclasts
Massive, medium-grained Qz Sandstone
Muddy intraclasts
Muddy intraclast
Massive, medium-grained Qz Sandstone
Braided/choti channels
Fluvial plain (bed-load channels)
Braided/choti channels
Fluvial plain (bed-load channels)

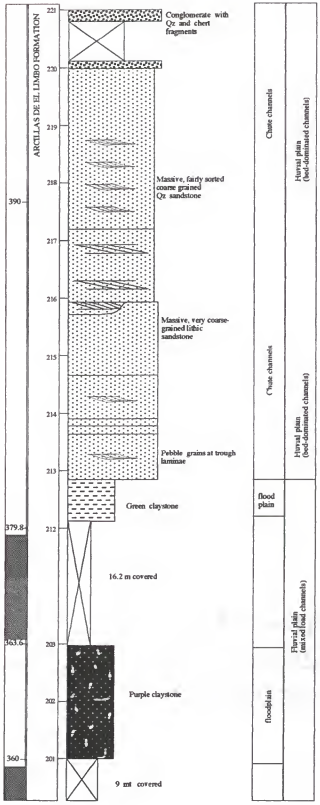

Muddy intraclast
Grey mudstone
45 m covered
Qz Sandstone
Qz Sandstone
Pebble grains
106.2
61.2
60
50
325
302
299
298
297
296
295
294
293
292
291
Floodplain
Braidedchans channels
Fluvial plain (bed-load channels)
Braidedchans channels
Fluvial plain (bed-load channels)

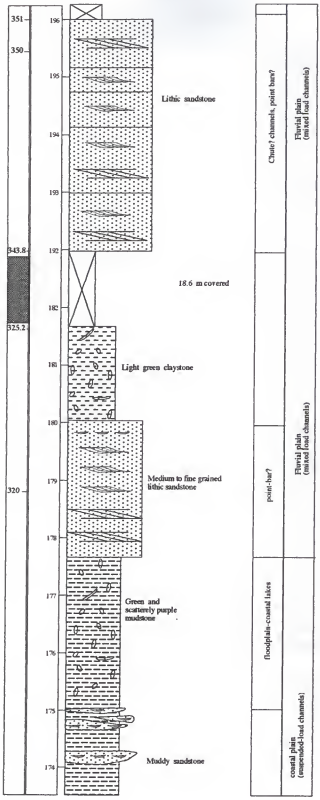

290
289
40
288
287
286
285
284
283
30
282
281
280
279
278
20
Course to conglomeratic Qz-sandstone.
Very course-grained Qz sandstone
Braided/chute channels
Fluvial plain (bed-load channels)
Braided/chute channels
Fluvial plain (bed-load channels)

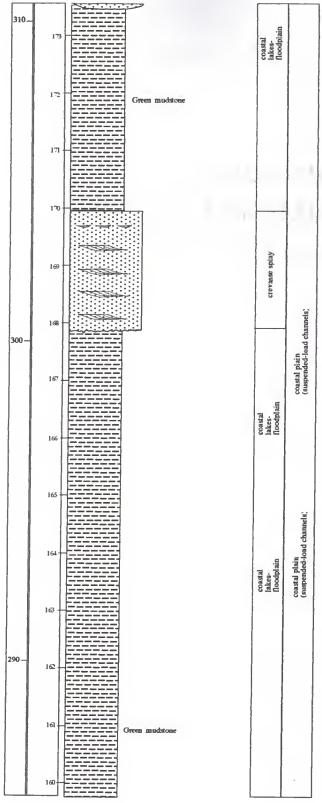

ARCILLAS DE EL LIMBO FORMATION
ARENISCAS DE EL LIMBO FORMATION
473.4
0
477
10
277
276
275
274
273
272
271
270
269
268
267
266
265
264
Conglomeratic to coarse Qz Sandstone
Well sorted, coarse yellow Qz sandstone
Red siltstone
Light grey claystone
Fine grained, grey Qz sandstone
Braided/chute channels
paleosol
over-bank
Fluvial plain (bed-load channels)
Braided/chute channels
Fluvial plain (bed-load channels)
Coastal plain (suspended-load channels)

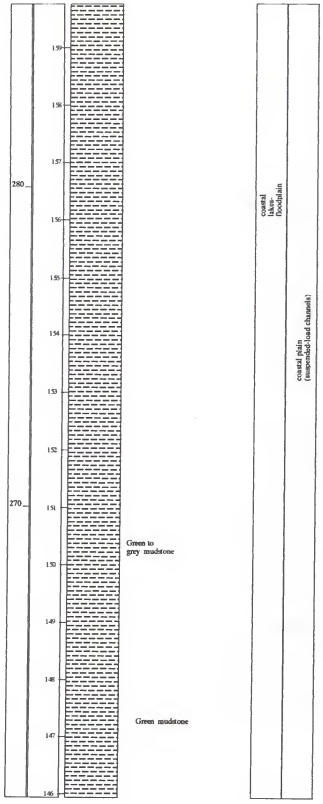

10.8 m Covered
462.6
460
450
440
238
257
256
255
254
253
252
251
250
249
248
247
246
green claystone
Green siltstone
Green siltstone
Purple claystone red mottled
Purple to green claystone red mottled
floodplain-coastal lakes
over-bank
over-bank
floodplain-coastal lakes
Coastal plain (suspended-load channels)
Coastal plain (suspended-load channels)

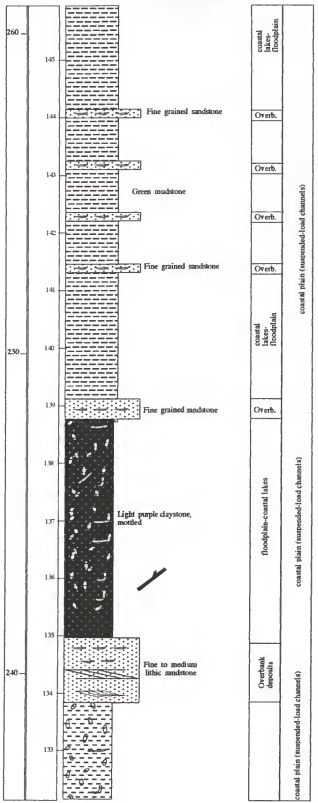

245
244
243
242
241
240
430
428.4
239
399
222
ARCILLAS DE EL LIMBO FORMATION
Purple claystone
Green claystone
29.4 m covered
floodplain-coastal lakes
Coastal plain (meandroid-lined channels)
Chute channels
Vertical plain
(Sand-dominated channels)

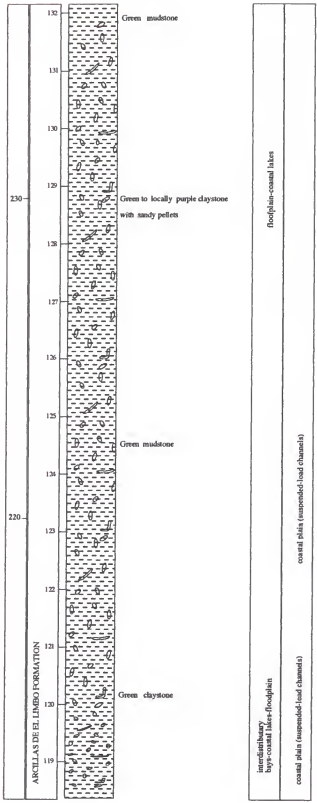

ARCILLAS DE EL LIMBO FORMATION
221
220
219
218
390
217
216
215
214
213
379.8
212
363.6
203
202
201
360
Conglomerate with Qz and chert fragments
Massive, fairly sorted coarse grained Qz sandstone
Massive, very coarse-grained lithic sandstone
Pebble grains at trough laminae
Green claystone
16.2 m covered
Purple claystone
9 mt covered
floodplain
Fluvial plain (Sand-dominated channels)
flood plain
Chute channels
Fluvial plain (Sand-dominated channels)
Chute channels
Fluvial plain (Sand-dominated channels)

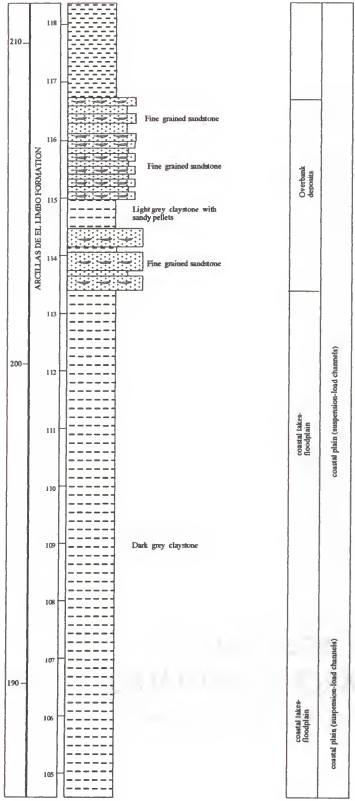

351
350
343.8
325.2
320
196
195
194
193
192
182
181
180
179
178
177
176
175
174
Lithic sandstone
18.6 m covered
Light green claystone
Medium to fine grained lithic sandstone
Green and scatterely purple mudstone
Muddy sandstone
Chute? channels, point bars?
Fluvial plain (meandering channels)
point-bar?
Fluvial plain (meandering channels)
Floodplain-coastal lakes
coastal plain (meandering-braid channels)

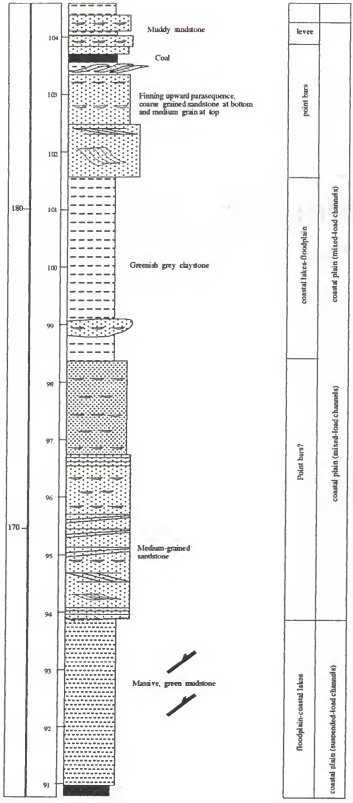

310
300
290
179
172
171
170
169
168
167
166
165
164
163
162
161
160
Green mudstone
Green mudstone
coastal lakes-floodplain
crevasse spay
coastal lakes-floodplain
coastal plain (supratidal flood channels;
coastal plain (supratidal flood channels;
coastal lakes-floodplain

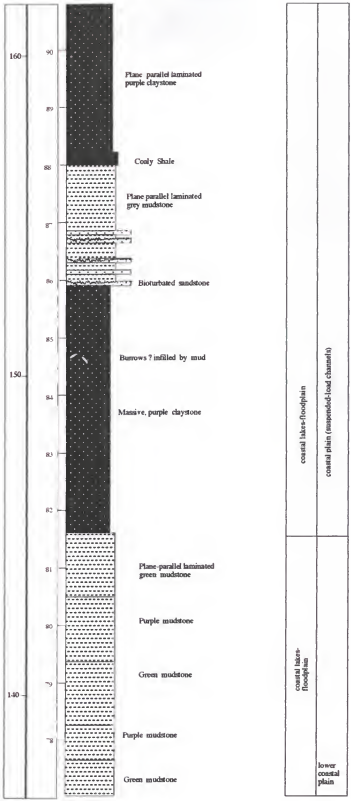

280
270
159
158
157
156
155
154
153
152
151
150
149
148
147
146
Green to grey mudstone
Green mudstone
coastal lakes-floodplain
coastal plain (meandrine/anastomosed channels)

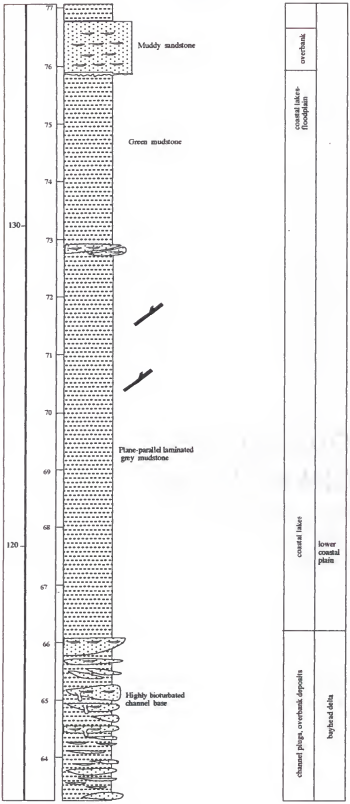

260
250
240
145
144
143
142
141
140
139
138
137
136
135
134
133
Fine grained sandstone
Green mudstone
Fine grained sandstone
Fine grained sandstone
Light purple claystone, mottled
Fine to medium lithic sandstone
Overb.
Overb.
Overb.
Overb.
Overb.
coastal lakes floodplain
coastal lakes floodplain
floodplain-coastal lakes
Overbank deposits
coastal plain (transcended load channels)
coastal plain (transcended load channels)
coastal plain (transcended load channels)

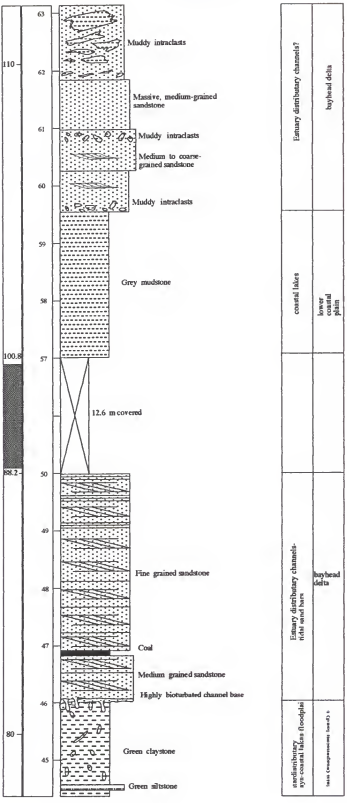

ARCILLAS DE EL LIMBO FORMATION
230
220
132
131
130
129
128
127
126
125
124
123
122
121
120
119
Green mudstone
Green to locally purple claystone
with sandy pellets
Green mudstone
Green claystone
interdistributary
bayst-coastal lakes-floodplain
floodplain-coastal lakes
coastal plain (suspended-load channels)
coastal plain (suspended-load channels)

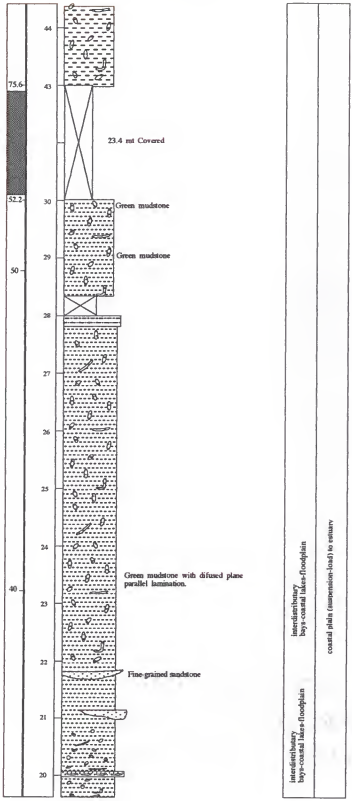

ARCILLAS DE EL LIMBO FORMATION
210
200
190
118
117
116
115
114
113
112
111
110
109
108
107
106
105
Fine grained sandstone
Fine grained sandstone
Light grey claystone with sandy pellets
Fine grained sandstone
Dark grey claystone
coastal lakes-floodplain
Overbank deposits
coastal plain (suspension-load channels)
coastal lakes-floodplain
coastal plain (suspension-load channels)

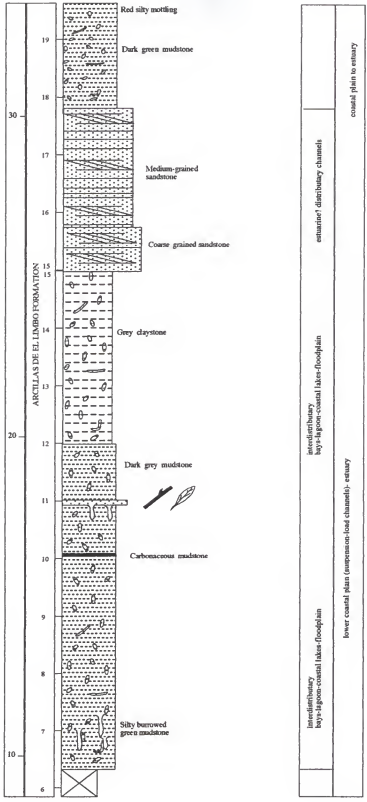

Muddy sandstone
Coal
Fining upward parasequence, coarse grained sandstone at bottom and medium grain at top
Greenish grey claystone
Medium-grained sandstone
Massive, green mudstone
180
170
104
103
102
101
100
99
98
97
96
95
94
93
92
91
levee
point bars
coastal lakes-floodplain
coastal plain (mixed-load channels)
Point bars?
coastal plain (mixed-load channels)
floodplain-coastal lakes
coastal plain (unmended-load channels)

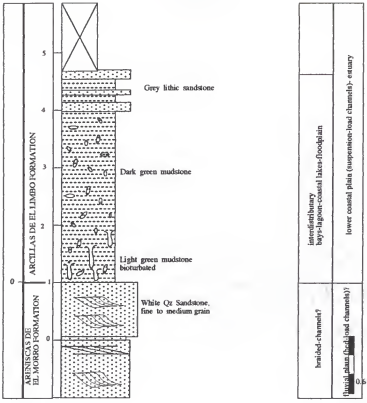

160
150
140
90
89
88
87
86
85
84
83
82
81
80
79
78
Plane parallel laminated purple claystone
Coaly Shale
Plane parallel laminated grey mudstone
Bioturbated mudstone
Burrows ? infilled by mud
Massive, purple claystone
Plane-parallel laminated green mudstone
Purple mudstone
Green mudstone
Purple mudstone
Green mudstone
coastal lakes-floodplain
coastal plain (suspended-load channels)
coastal lakes-floodplain
lower coastal plain


77
76
75
74
130
73
72
71
70
69
68
120
67
66
65
64
Muddy sandstone
Green mudstone
Plane-parallel laminated grey mudstone
Highly bioturbated channel base
coastal lakes-floodplain
overbank
coastal lakes
lower coastal plain
channel plugs, overbank deposits
hyperpycnal delta

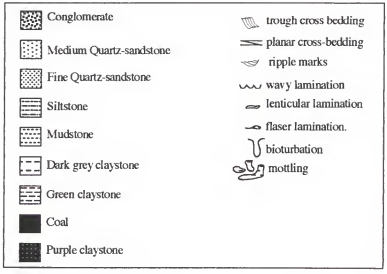

110
100.8
88.2
80
63
62
61
60
59
58
57
50
49
48
47
46
45
Muddy intraclasts
Massive, medium-grained sandstone
Muddy intraclasts
Medium to coarse-grained sandstone
Muddy intraclasts
Grey mudstone
12.6 m covered
Fine grained sandstone
Coal
Medium grained sandstone
Highly bioturbated channel base
Green claystone
Green siltstone
Estuary distributary channel?
buyhead delta
coastal lakes
lower coastal plain
Estuary distributary channels-tidal sand bars
buyhead delta
swollen/estuary-syn-coastal lakes-floodplain


75.6
52.2
50
40
44
43
30
29
28
27
26
25
24
23
22
21
20
23.4 mt Covered
Green mudstone
Green mudstone
Green mudstone with difused plane parallel lamination.
Fine-grained mudstone
intradelthaic bayu-coastal lake-floodplain
lower-delta bayu-coastal lake-floodplain
coastal plain (immersion-load) to estuary

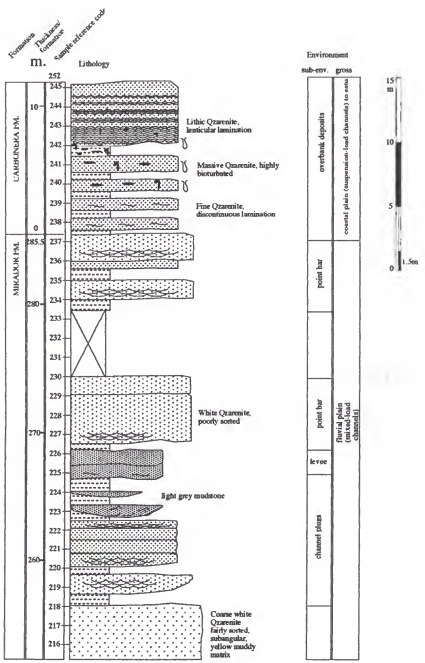

ARCILLAS DE EL LIMBO FORMATION
Red silty mottling
Dark green mudstone
Medium-grained sandstone
Coarse grained sandstone
Grey claystone
Dark grey mudstone
Carbonaceous mudstone
Silty burrowed green mudstone
interdistributary bay/lagoon/coastal lake/floodplain
estuarine? distributary channels
coastal plain to estuary
interdistributary bay/lagoon/coastal lake/floodplain
lower coastal plain (interdistributary bay/lagoon/coastal lake/floodplain) to estuary

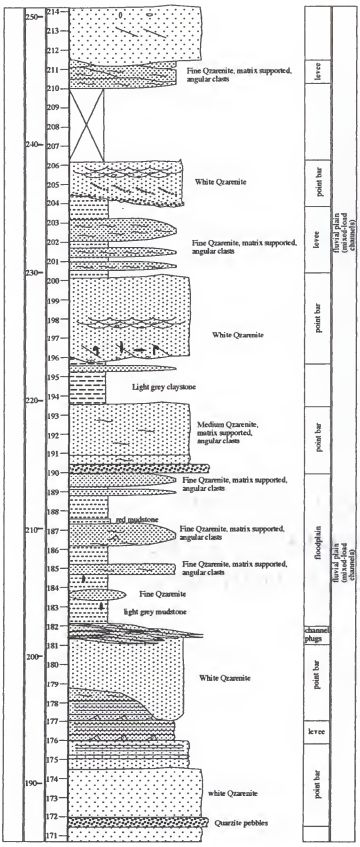


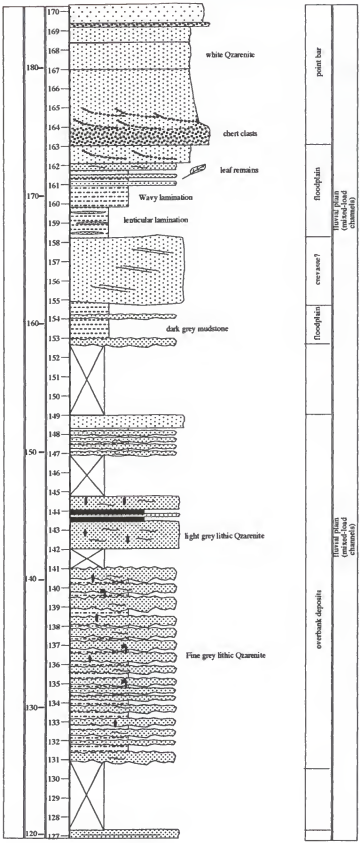
Key to lihological symbols

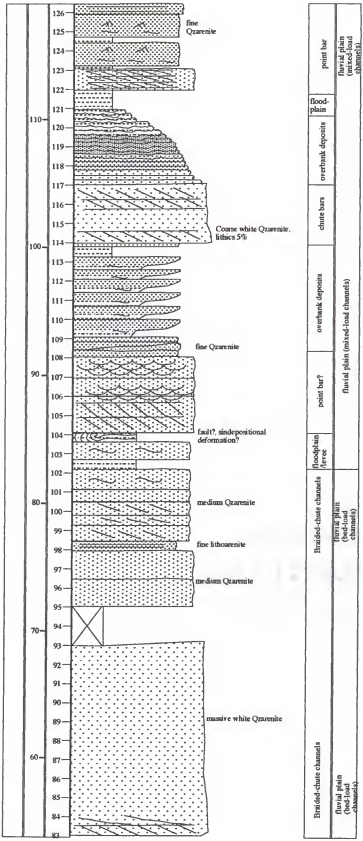


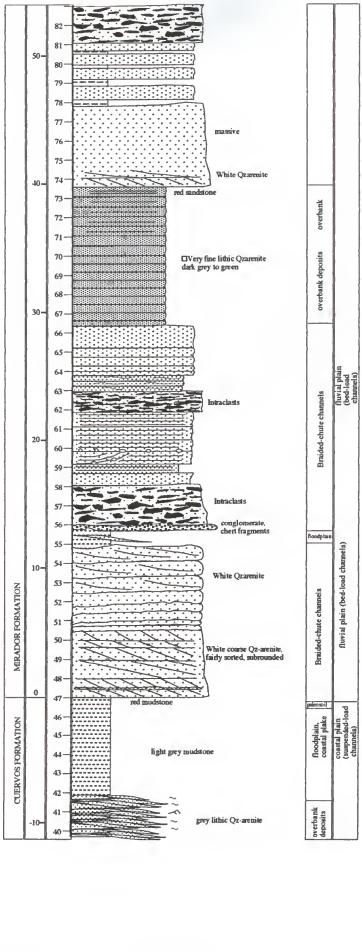
APPENDIX C
LITHOLOGICAL DESCRIPTION OF THE REGADERA SECTION

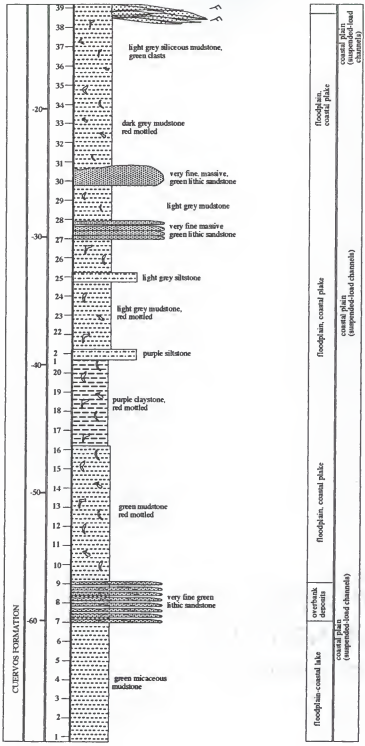



?
Fine Qtzarenite, matrix supported, angular clasts
White Qtzarenite
Fine Qtzarenite, matrix supported, angular clasts
White Qtzarenite
Light grey claystone
Medium Qtzarenite, matrix supported, angular clasts
Fine Qtzarenite, matrix supported, angular clasts
red mudstone
Fine Qtzarenite, matrix supported, angular clasts
Fine Qtzarenite, matrix supported, angular clasts
Fine Qtzarenite
light grey mudstone
White Qtzarenite
white Qtzarenite
Quartzite pebbles
levee
point bar
point bar
levee
point bar
floodplain
channel plugs
point bar
levee
point bar
fluvial plain (meandered channels)
fluvial plain (meandered channels)

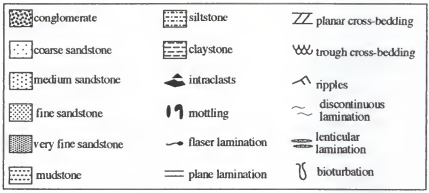

170
169
168
180
167
166
165
164
163
162
161
170
160
159
158
157
156
155
160
154
153
152
151
150
149
148
350
147
146
145
144
143
142
141
140
140
139
138
137
136
135
134
130
133
132
131
130
129
128
120
127
white Qzarenite
chert clasts
leaf remains
Wavy lamination
lenticular lamination
dark grey mudstone
light grey lithic Qzarenite
Fine grey lithic Qzarenite
overbank deposits
floodplain
crevasse?
floodplain
point bar
fluvial plain
(mixed-load
channels)
fluvial plain
(mixed-load
channels)


fine Qzarenite
Coarse white Qzarenite, lithics 5%
fine Qzarenite
fault?, sindepositional deformation?
medium Qzarenite
fine lithoarenite
medium Qzarenite
massive white Qzarenite
Braided-chute channels
fluvial plain (mixed-load channels)
floodplain fines
point bar?
overbank deposits
chute bars
overbank deposits
floodplain
point bar
fluvial plain (mixed-load channels)
fluvial plain (mixed-load channels)

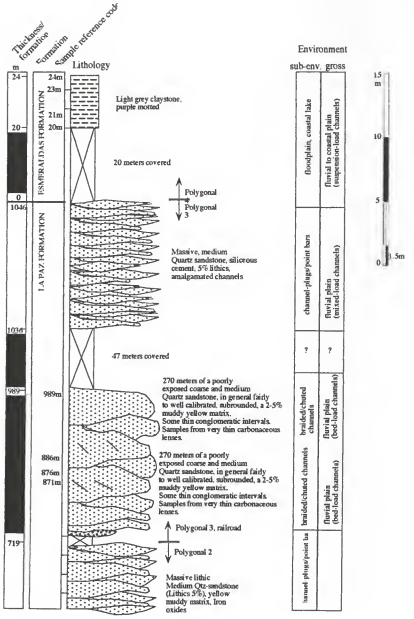

CUERVOS FORMATION
MERADOR FORMATION
-10
0
10
20
30
40
50
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
69
70
71
72
73
74
75
76
77
78
79
80
81
82
red mudstone
White coarse Qz-arenite, fairly sorted, subrounded
White Qzarenite
conglomerate, chert fragments
Intraclasts
Intraclasts
LIVery fine lithic Qzarenite dark grey to green
red mudstone
White Qzarenite
massive
light grey mudstone
grey lithic Qz-arenite
paleosol
floodplain
overbank deposits
floodplain, coastal plain
coastal plain (fluvial and tidal channels)
Braided-chute channels
Braided-chute channels
fluvial plain (bed-load channels)
fluvial plain (bed-load channels)
overbank deposits
overbank
overbank deposits
fluvial plain (bed-load channels)

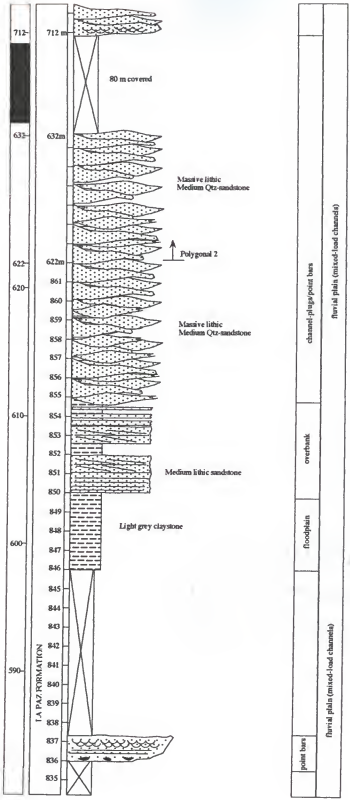

CUERVOS FORMATION
light grey siliceous mudstone, green chalts
dark grey mudstone red mottled
very fine, massive, green lithic sandstone
light grey mudstone
very fine massive green lithic sandstone
light grey siltstone
light grey mudstone, red mottled
purple siltstone
purple claystone, red mottled
green mudstone red mottled
very fine green lithic sandstone
green micaceous mudstone
floodplain-coastal lake
overbank deposits
floodplain, coastal plain
floodplain, coastal plain
coastal plain (unconfined-load channels)
floodplain, coastal plain
coastal plain (suspended-load channels)
coastal plain (unconfined-load channels)

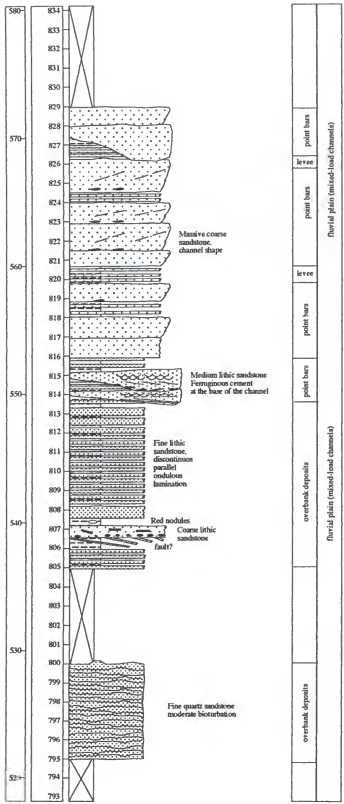
Key to lithologic symbols

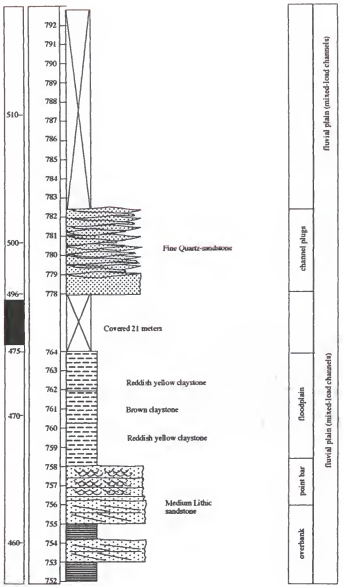


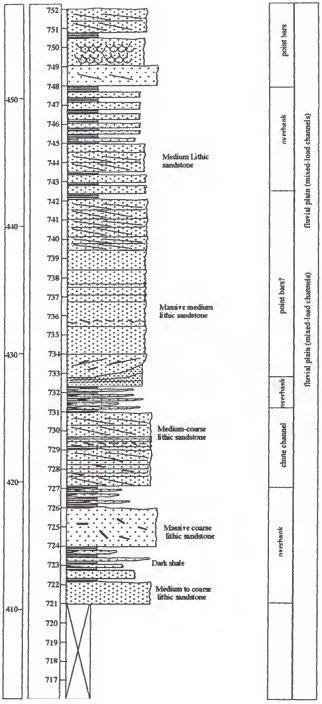
APPENDIX D
LITHOLOGICAL DESCRIPTION OF THE URIBE SECTION

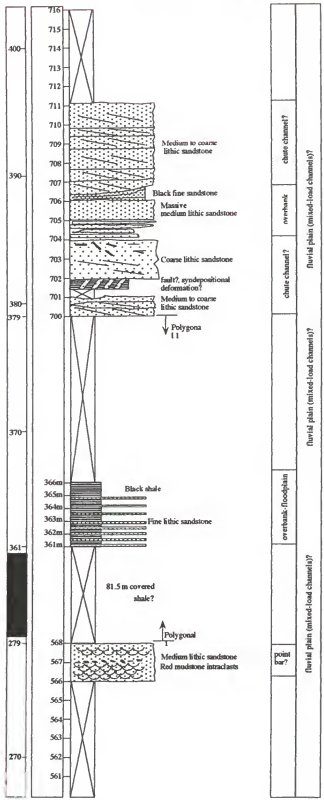


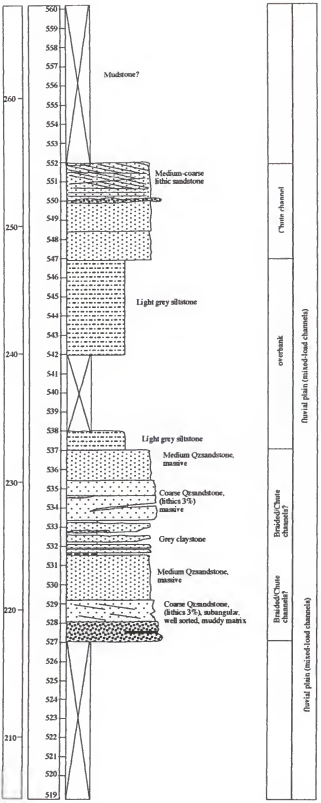

712
633
622
620
610
600
590
LA PAZ FORMATION
712 m
80 m covered
632m
Massive lithic
Medium Qtz-sandstone
Polygonal 2
622m
861
860
859
858
857
856
855
854
853
852
851
850
849
848
847
846
845
844
843
842
841
840
839
838
837
836
835
Massive lithic
Medium Qtz-sandstone
Medium lithic sandstone
Light grey claystone
point bars
floodplain
overbank
channel-plug/point bars
fluvial plain (mixed-load channels)
fluvial plain (mixed-load channels)

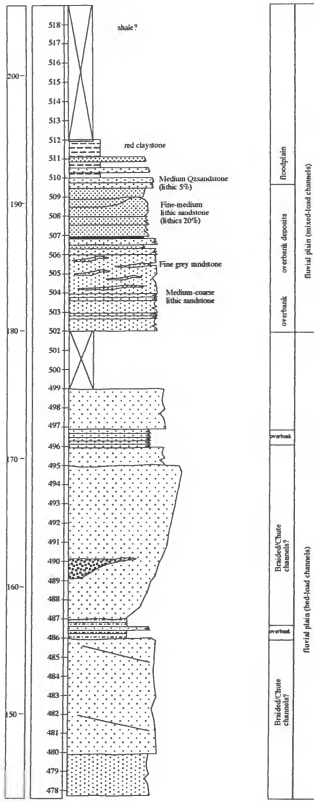

580
570
560
550
540
530
521
834
833
832
831
830
829
828
827
826
825
824
823
822
821
820
819
818
817
816
815
814
813
812
811
810
809
808
807
806
805
804
803
802
801
800
799
798
797
796
795
794
793
Massive coarse sandstone, channel shape
Medium lithic sandstone Ferruginous cement at the base of the channel
Fine lithic sandstone, discontinuous parallel undulous lamination
Red nodules
Coarse lithic sandstone
fault?
Fine quartz sandstone moderate bioturbation
overbank deposits
overbank deposits
point bars
levee
point bars
levee
point bars
point bars
point bars
overbank deposits
fluvial plain (mixed-load channels)
fluvial plain (mixed-load channels)

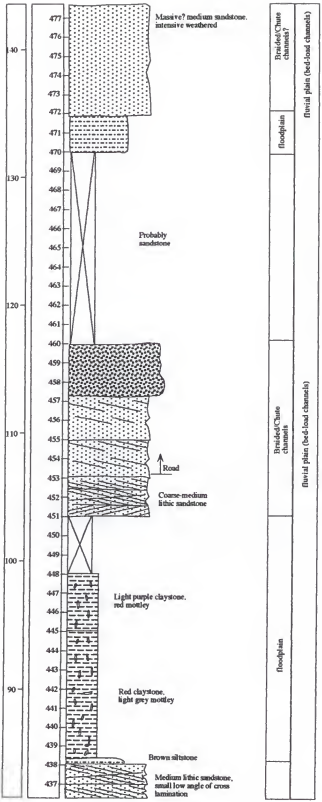

510
500
496
475
470
460
792
791
790
789
788
787
786
785
784
783
782
781
780
779
778
764
763
762
761
760
759
758
757
756
755
754
753
752
Fine Quartz-sandstone
Covered 21 meters
Reddish yellow claystone
Brown claystone
Reddish yellow claystone
Medium Lithic sandstone
overbank
point bar
floodplain
channel plugs
fluvial plain (limited-load channels)
fluvial plain (mixed-load channels)

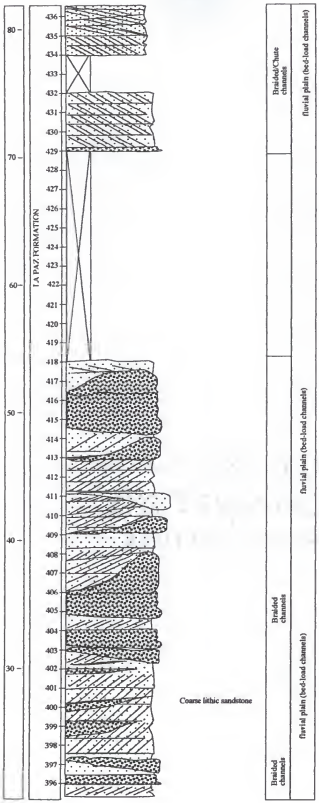

752
751
750
749
748
450
747
746
745
744
743
742
741
440
740
739
738
737
736
735
734
430
733
732
731
730
729
728
727
420
726
725
724
723
722
721
410
720
719
718
717
Medium Lithic sandstone
Massive medium lithic sandstone
Medium-coarse lithic sandstone
Massive coarse lithic sandstone
Dark shale
Medium to coarse lithic sandstone
overbank
chute channel
overbank
point bars?
fluvial plain (mixed-load channels)
overbank
point bars
fluvial plain (mixed-load channels)


716
715
714
713
712
711
710
709
708
707
706
705
704
703
702
701
700
400
390
380
379
370
366m
365m
364m
363m
362m
361m
361
279
568
567
566
565
564
563
562
561
270
Medium to coarse lithic sandstone
Black fine sandstone
Massive medium lithic sandstone
Coarse lithic sandstone
Fault?, syndepositional deformation?
Medium to coarse lithic sandstone
Polygona 11
Black shale
Fine lithic sandstone
81.5 m covered shale?
Polygonal
Medium lithic sandstone
Red mudstone intraclasts
point bar?
overbank-floodplain
overbank
chute channel?
chute channel?
fluvial plain (mixed-load channels)?
fluvial plain (mixed-load channels)?
fluvial plain (mixed-load channels)?


260
250
240
230
220
210
Mudstone?
Medium-coarse lithic sandstone
Light grey siltstone
Light grey siltstone
Medium Qzsandstone, massive
Coarse Qzsandstone, (frtfacs 3%) massive
Grey claystone
Medium Qzsandstone, massive
Coarse Qzsandstone, (frtfacs 3%), subangular, well sorted, muddy matrix
Braided/Chute channels?
Braided/Chute channels?
overbank
Chute channel
fluvial plain (mixed-load channels)
fluvial plain (mixed-load channels)


shale?
red claystone
Medium Qzsandstone (lithic 5%)
Fine-medium lithic sandstone (lithics 20%)
Fine grey mudstone
Medium-coarse lithic sandstone
overbank
overbank deposits
floodplain
fluvial plain (mixed-load channels)
Braided/Chute channels
fluvial plain (bed-load channels)


Massive? medium sandstone, intensive weathered
Probably sandstone
Road
Coarse-medium lithic sandstone
Light purple claystone, red mottley
Red claystone, light grey mottley
Brown siltstone
Medium lithic sandstone, small low angle of cross lamination
floodplain
Braided Chute channel
fluvial plain (bed-load channels)


80
70
60
50
40
30
436
435
434
433
432
431
430
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428
427
426
425
424
423
422
421
420
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415
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413
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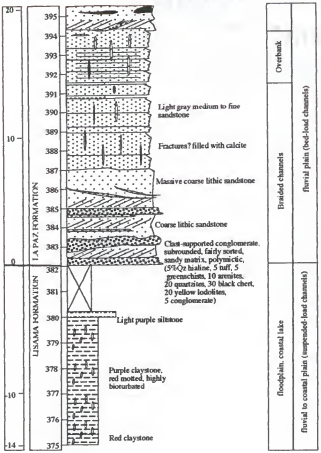
411
410
409
408
407
406
405
404
403
402
401
400
399
398
397
396
I A PAJ FORMATION
Coarse lithic sandstone
Braided channels
Braided/Chute channels
fluvial plain (bed-load channels)
fluvial plain (bed-load channels)



Key to lithology

intraclasts	conglomerate
mottling	coarse sandstone
flaser lamination	medium sandstone
plane-parallel lamination	fine sandstone
planar cross-bedding	very fine sandstone
trough cross-bedding	mudstone
ripples	siltstone
discontinuous lamination	claystone
lenticular lamination	shale

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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August 1999

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